A
MODERN GEOGRAPHY

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VOLUME I.

GENERAL AND PHYSICAL GEOGRAPHY

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PREFACE

In preparing this book I have done my utmost to justify its title by making it in every way modern, not merely by the inclusion of up-to-date information and figures but by a modern treatment of the subject. I have sought throughout to avoid too bare a presentation of facts and figures by constantly relating them to human life and customs, and I have relied on the never-failing attraction of the human element to sustain the reader's interest and to assist him to an understanding of the geographical background.

Events of the past two decades have brought about such a widespread modification of world economic conditions that the work of the geographer is now far more difficult than it must have been in a more normal period. Changes in political boundaries, movements of population, the development of new lines of communication and sources of power, and a re-shuffling of industrial and agricultural occupations in the various countries, have in many cases necessitated an almost entirely new viewpoint. Nevertheless, I have endeavoured to portray these and other changes so as to give the reader a true picture of existing world conditions.

Of the innumerable works of reference to which I have resorted for information and assistance, to none do I owe a greater debt of gratitude than to Chisholm and Stamp's "*Handbook of Commercial Geography*". Other works which I have consulted with profit are "*The International Year-Book of Agricultural Statistics*", "*The Statesman's Year-Book*", "*The Commerce Year-Book*" (*U.S.A.*), "*The Mineral Industry of the British Empire and Foreign Countries*" (published by the Imperial Institute), and "*The Statistical Year-Book of the League of Nations*".

The Trade Supplements published by the "*Times*" and other newspapers and the Year-Books of the British Dominions have also provided me with a mine of useful information.

At the end of each chapter will be found a number of typical examination questions taken from the papers set by the various examining bodies mentioned on page xi. To all of these acknowledgment is due and is here accorded. Acknowledgment is also made to the Controller of H.M. Stationery Office for his permission to include numerous questions from Civil Service Examination Papers.

My grateful thanks are due and are here accorded to Mr. T. M. Keeling for much valuable assistance during the preparation of this work, and to Mr. J. Martin, B.Sc. (Dunelm), for reading through the proofs and for making a number of helpful suggestions.

S. E. T.

September, 1938.

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KEY TO ABBREVIATIONS USED IN THE EXAMINATION QUESTIONS

B.U. . . .	Bristol University.
C.C.S. . . .	Corporation of Certified Secretaries.
C.I.I. . . .	Chartered Insurance Institute.
C.I.S. . . .	Chartered Institute of Secretaries.
C.S. . . .	Civil Service Commission.
C.S.C. . . .	Cambridge Schools Certificate.
C.W.B. . . .	Central Welsh Board.
D.S.C. . . .	Durham Schools Certificate.
D.U. . . .	Durham University Matriculation.
I. of B. Qual. . .	Institute of Bankers, Qualifying.
I. of B. P.I. . .	do. do. Part I.
I.C.W.A. . . .	Institute of Cost and Works Accountants
I.S.A. . . .	Incorporated Secretaries Association.
L.A.A. . . .	London Association of Accountants.
L.C. of C. . .	London Chamber of Commerce.
L.G.S. . . .	London General Schools Certificate.
L.M. . . .	London University Matriculation.
N.U. . . .	Northern Universities Matriculation.
O.L. . . .	Oxford Local.
O.S.L. . . .	Oxford Schools Leaving Certificate.
O. & C.J.B. . .	Oxford and Cambridge Joint Board Matriculation.
R.S.A. . . .	Royal Society of Arts.
S.A.A. . . .	Society of Incorporated Accountants and Auditors.

GENERAL AND PHYSICAL GEOGRAPHY

CHAPTER 1

INTRODUCTORY

UNTIL comparatively recently, the study of Geography implied little more than the memorising of such facts as the lengths of rivers, the heights of mountains, the names of bays and peninsulas and the depths of lakes and seas. To-day, it is realised that such feats of memory alone are of little practical value to the student of Geography. The knowledge of the situation and name of a bay or gulf is relatively unimportant unless it is joined with the knowledge that the bay or gulf shelters a port which has assumed economic or political prominence. From the standpoint of modern Geography, even the finest bay in the world can have little real significance unless its "hinterland", *i.e.*, the land immediately behind it, is productive, or unless some artificial or natural factor makes it the inevitable site of a port. Southampton, for instance, has achieved importance despite its poor hinterland because the double tides of Southampton Water enable the largest ocean-going ships to enter and leave the port at any time.

This well-known example serves to demonstrate the fact that the study of Geography as we know it to-day is a search for *causes*; a constant attempt to discover the why and wherefore of geographical facts, as well as the geographical factors influencing human problems. The student of Geography must not be satisfied with knowing that a certain country produces large quantities of some commodities and very little of others; he must find out *why* this is so. *Every geographical condition can be traced back to a cause.* What reasons underly the fact that British ports are ice-free throughout the winter? What are the root causes of the great difference between the density of population in the United States and that in Australia? If we are enabled by our study of Geography to answer these and similar questions convincingly, we shall know that our work is proceeding on the right lines.

Even as recently as two decades ago Geography was usually defined as "A description of the world and of the people who inhabit the world." To-day, however, Geography is regarded as an *enquiry*, of which the central figure is man. It enquires into the causes which determine where man lives, and how he lives; why some places have a

dense population, whilst others are sparsely inhabited; why in some parts of the world man is engaged primarily in agricultural pursuits, whilst in others he is occupied in mining or manufacture. Clearly, in the light of these conceptions we may define Geography as "*An enquiry into the causes or factors influencing the distribution and activities of man on the earth.*" It is a scientific study of the action of man on and his reaction to his physical, social and psychological environment or surrounding.

To make our enquiry complete, we have to utilise the conclusions of such sciences as Biology, Geology, Economics and Meteorology. We must also have a clear understanding of the plan of the earth, of the earth's relation to the solar system and of certain other essential and fundamental facts which are dealt with in the first part of this book.

Factors Influencing the Distribution and Activities of Man

The main factors influencing the life of man on the earth may conveniently be divided into four groups:

1. PHYSICAL FEATURES } These are by far the most important.
2. CLIMATE }
3. VEGETATION—which is controlled by physical features and climate.
4. ANIMAL LIFE. The type of animal life in any region is controlled by the type of vegetation in that region, and ultimately, of course, by physical features and climate.

Physical Features

The formation of the surface of the land has a very important influence on man's capacity for work, as well as on his habits, occupations and mode of living. Mountain ranges, such as the great wall of the Rocky Mountains in North America and the Himalayas to the north of India, not only have been a serious hindrance to communication in the past, but also play an important part in controlling the climate of the regions they flank. Moreover, mountains are often valuable sources of mineral wealth (as the Hartz Mountains of Germany); of water-power (as are the mountains of Italy); and as a means of trapping water which is drawn up through artesian wells in adjacent plains or basins (as in Australia); while the rivers which exercise such a vitally important influence on a country's economic life usually have their sources in mountain ranges to which they owe both their volume and power (head of water).

The importance of a river depends mainly on its use as a means of communication; for not only may a river in itself be an important means of water transport, but its valley may greatly facilitate land transport, as is the case with the Danube in Europe, the Irawadi in Burma and the Hudson in the United States. Even rivers such as

the vast Zambesi, which are obstructed by falls or rapids, or rivers such as those of Peninsular India, which flow in deep ravines or cañons, may have great economic value, for though they may be useless for transport purposes, they may nevertheless contribute greatly to a country's wealth by supplying an abundance of cheap water-power.

In some cases, both rivers and mountain ranges fulfil a useful function in clearly defining political boundaries. The Rhine forms a definite boundary for a long distance between Germany and France; the Pyrenees clearly divide Spain from France. Then again, the delta of a river, *i.e.*, the area comprising the mouth of a river which enters the sea through many channels, may assume great geographical importance; as, for example, the delta of the Nile in Egypt, which is the most fertile, productive and densely populated part of the country.

Plateaus (*i.e.*, high plains rising on all sides from lower ground), are an example of what may be termed "detrimental geographical control." Such plateaus as that of South Africa not only hinder railway construction from the coast inland, but also are liable to drought and desert conditions, while their rivers, owing to their steep descent to the sea, are useless as a means of communication.

On the other hand, plains with favourable climatic conditions, such as the great inland plains of North America, provide valuable land for cattle grazing and for cultivation, and are consequently among the world's main sources of food supply. Naturally, the economic value of a plain is enhanced if the evenness of its surface makes possible the use of modern agricultural machinery and the building of railways, as is strikingly the case in Canada, in the United States, in the Argentine and in Australia. Canal construction also is facilitated, as on the Great European Plain.

Climate

Climate is an extremely important geographical factor. It not only determines to a large extent the sources of the world's food supplies, but it also influences the habits and productive capacity of man in different parts of the world. The great hot deserts (such as the Sahara of Northern Africa, the Kalahari of South Africa and the Australian Desert) owe their existence mainly to climatic causes, for their non-productiveness is usually due, not to infertility of the soil, but, as we shall see later, to lack of water. Conversely, the great food-producing capacity and profuse vegetation of the "monsoon" lands (such as India) is also due to climatic causes, the chief of which is the heavy rainfall during the growing season.

In some cases, man has found it possible to modify the adverse effects of climatic influences; as, for example, by the great irrigation schemes in India, Egypt and elsewhere, whereby land which was previously barren has been made exceedingly productive.

The direct influence of climate on man's capacity for work becomes apparent when we compare the energy and activity of the inhabitants of different parts of the world. The profuse growth of equatorial lands makes food-getting a matter of comparative ease, and this, combined with the great heat, tends to sap the energy of the inhabitants and to make them indolent and more degenerate than the natives of other regions, especially those of the "temperate" countries, where the climate is more "energising" than anywhere else in the world. In Britain, for example, the equable climate is, on the whole, conducive to hard work. The heat of the summer is never sufficiently intense to cause a serious break in industrial activity, while the winters are never so severe as to prevent man from working continuously without undue hardship.

Vegetation

The type of vegetation in any region is controlled partly by physical features and partly by climate. In mountainous regions, vegetation becomes sparser as the height of the land increases. Further, the windward side of a mountain range frequently has a type of vegetation entirely different from that of the leeward slopes, because the former benefits to a greater degree from the rain brought by winds, which, on coming into contact with the high land, are forced upwards and compelled to deposit most of their moisture. The windward slopes of the high western mountains of North America receive an abundant rainfall; they are clothed with valuable trees while, on the lower slopes, fruit farming is a profitable occupation. On the other hand, the land to the east of these mountains is practically treeless; its natural vegetation consists mainly of grasses and other herbaceous plants, while its main industries are cereal cultivation and cattle ranching.

The profuse vegetation of countries near the Equator is likewise due solely to climatic causes. The constant heat and rain of the basins of the Amazon in South America and of the Congo in Africa have produced a mass of forest vegetation of such intensity that even to-day these regions are little explored, and, except in a few isolated parts, Nature still remains unconquered by man. No doubt in time these regions, too, will be developed commercially, but it will be at great cost—both in money and in human life.

The regions known as the "tundra", comprising the cold deserts of the Polar region within or near the Arctic Circle, provide a type of vegetation in direct contrast to that of the equatorial lands, and here, again, climatic factors are responsible. The vegetation consists of short shrubs, mosses and lichens. In the winter, the land area is a frozen waste, with little sign of life. In the short summer, however, the surface becomes a swamp. Then, as the sunshine increases, dormant nature springs to life, the ground becomes covered with stunted

vegetation and flowers, and the few inhabitants crawl from their winter quarters to search for food to store up against the next long winter.

Animals

Although the distribution of animals is directly controlled by the type of vegetation, it is indirectly and primarily controlled by physical features and climate. The camel, which can travel for many days without water, is always associated with hot desert areas, where the aridity is entirely due to climatic influences. The distribution of sheep, and consequently the sources of our wool supply, depends on both climate and physical features. Sheep do not like much heat or damp, and in tropical regions, therefore, they thrive only where the heat is tempered by altitude—where the combined influences of physical features and climate favour their development.

Collective Influence of the Factors on Man

Although no geographer believes that the habits of man are *entirely* influenced by the factors here enumerated, he does contend that they exert the *primary* influence on the occupations and settlement of man in different parts of the world. True, there are other factors. The "political" factor, for example, may seriously retard economic progress, as witness the political unrest in China, which has mainly prevented the rational development of that country's vast resources. Conversely, inventions and improvements may promote rapid development; as, for instance, the great inventions in textile machinery which a century ago revolutionised our cotton and other textile industries, and the more recent improvements in various modes of transport, which have greatly facilitated travel for business and pleasure, and have markedly stimulated race transference and colonisation throughout the world.

The world's great hot deserts remain practically uninhabited because, without artificial means involving great expense, they give no return for any labour expended on their cultivation. Only in those places where underground water has welled to the surface is any settled life possible. On the other hand, the great plains, which support numerous herds of cattle and produce large quantities of foodstuffs, attract farmers and immigrants in great numbers, while in places which are favourably situated, towns spring up as marketing and distributing centres. In many cases these centres develop with great rapidity and attract large populations, *e.g.*, Winnipeg, which distributes the produce of the Canadian prairies and has had a phenomenal growth largely as a result of its markedly advantageous situation.

In another direction we find physical or climatic influences behind the establishment and growth of leading industrial centres. Without exception, all the great developed coalfields of the world support important industrial towns. Lancashire, with the advantages not only

of a coalfield and good sea access, but also of a damp climate especially favourable to cotton spinning, was enabled to place herself in the forefront of the world's cotton industry. Some of the raw cotton was, and still is, imported from such distant countries as India and Egypt, where climatic conditions, though eminently suitable for the growth of cotton, are unsuited (*unless mechanically modified*) to its manufacture into yarn and cloth.

When deposits of precious metals, especially gold, are discovered, people are very strongly attracted to the scene, but the first effect is only transitory. The *secondary effects*, however, are often far-reaching. In Australia, for example, the early discoveries of gold caused great rushes to the vicinity of the finds, but, when the first rushes were over, many of the unsuccessful people who had crowded to the gold-mining districts had no means of returning to their homes and so were forced to stay on the land as farmers. Later, railways were built from the ports to the mining and farming centres, and large areas of the country were thus made accessible for further development.

It has already been observed that climatic conditions in equatorial countries have a marked influence on human physical and mental capacity, making the inhabitants indolent and far less progressive than the peoples of the temperate regions. Largely because of this, a great part of the land in the tropical and sub-tropical areas of the world has been more or less forcibly acquired by the nations of the temperate zones. Moreover, climatic conditions, combined with the disinclination of the people to emigrate and the refusal of other countries to admit immigrants from such lands, have given the monsoon lands a dense population—denser sometimes than can be supported. On the other hand, the energy of the inhabitants of the temperate lands has caused them to develop rapidly, while the compelling forces of ambition and industrial growth have led them to look for new lands to conquer and to develop. They have thus inherited a roving, adventurous spirit which has made them a much more potent force in the world than the peoples of warmer and more luxuriant climes.

These brief introductory remarks will demonstrate that our task of analysing in greater detail the various geographical factors which influence the life of man is no light one. In the first place we must acquaint ourselves with the various phenomena which arise from the fact that the world is only part of a much larger universe. We must learn the causes of day and night and of the seasons. Aids to the study of geography, such as map making and map reading, are an essential part of our equipment, and they, together with all related facts and phenomena, must be briefly reviewed. In this way we shall build for ourselves a sound knowledge of geographical principles, and, so armed, we may safely proceed to a study of the economic development of the various countries of the world.

CHAPTER 2

MATHEMATICAL GEOGRAPHY

THE UNIVERSE

The Stellar System

The Stellar System, consisting of major and minor planets, and millions of stars, is the name given to the aggregate of all those bodies which together make up the universe. The planets and the stars appear to the naked eye of an observer on the earth to be situated at the same distance from the point of observation, but actually they are at vastly differing distances from the earth. This fact can best be appreciated from the statement that the light from the moon, the nearest of these bodies, situated at a distance of 239,000 miles, takes less than one-and-a-half seconds to reach the earth (light travels at 186,000 miles per second), whereas that from the most distant body known to astronomers takes 140,000 years to reach us.

The heavenly bodies are divided into two main groups—the " fixed " stars, which appear always to maintain the same relative position, and the " planets ", which are continuously revolving round the sun, and which, with the sun, form the " Solar System."

The Solar System

Around the sun, the centre of the solar system, nine major planets and thousands of minor planets, all receiving their light from the centre body, revolve in oval-shaped orbits at varying distances. The major planets, in the order of their increasing distance from the sun, are Mercury, Venus, the Earth, Mars, Jupiter, Saturn, Uranus (which is only just visible to the naked eye), Neptune and Pluto (the last two being invisible to the naked eye). Venus, Mars and Mercury are smaller than the earth whilst the remaining planets are larger.

Six of the major planets have " satellites ", including the Earth, which has a satellite, the Moon, and each of such groups forms a separate system. The heavenly bodies known as *comets*, which revolve round the sun in elliptical orbits at varying distances, may also be regarded as members of the solar system. The comets are seen at regular

intervals, ranging from three to eighty years or more, and are visible only for a relatively short period.

The Sun

The Sun, the fixed star from which we receive that light and heat without which life would be impossible, is nearly 93,000,000 miles away, and its diameter is more than one hundred times greater than the diameter of the earth. So far as we can tell, the sun is an extremely hot body of incandescent gaseous matter. Distributed over its surface are peculiar markings, probably gaseous cavities, known as *sunspots*, from an observation of which it has been possible to determine that the time of duration of the sun's rotation on its axis is about 25⅓ days.

The Moon

The Moon, the one satellite of the earth, is about 2,160 miles in diameter, and is situated at a distance of about 239,000 miles from the earth. This distance is so insignificant in comparison with that of the sun from the earth that the moon appears to us to be quite as large as the sun though actually it is far from being so.

The moon revolves round the earth once every lunar month, *i.e.*, every 27⅓ days, and during the same time revolves completely round on its own axis. But though the moon presents the whole of its surface in turn to the sun, it presents only one side of its surface to the earth. This fact is illustrated in Fig. 1, from which it will be seen that on the moon's surface point A is always facing the earth as the moon revolves on its axis AB around its orbit, *i.e.*, the path it follows round the earth. Each of the points, B, D, A and C (in that order) is, however, presented in turn to the sun.

The moon is not a glowing fiery ball like the sun; on the contrary, it is dead and cold, and we see it only because its surface is lit up by the sun. But only the side of the moon facing the sun is lighted up; the other side is in darkness and invisible, and the so-called "phases of the moon" take place because we on the earth are able from time to time to see different proportions of the lighted-up surface.

In position 1 the dark side of the moon faces the earth and the moon is invisible. Then we have "new-moon"—really no moon at all. In position 2, which the moon reaches three days later, only a crescent can be seen by anyone on the earth; the rest is still in darkness. When position 3 is reached half the moon can be seen, and, finally, in position 5 the whole of the illuminated face is showing and we have "full moon". Up to this point the moon is said to be "waxing", but thereafter on to position 1 again, the moon is said to be "waning", for the portion visible is growing gradually less. It is when the moon is lit up we see the

so-called " Man in the Moon ", whose features are, of course, always the same because the moon presents to us only one of her surfaces.

The *full* moon and *new* moon occur when the sun, moon and earth are in an apparently straight line : *new* moon when the moon is between the sun and the earth ; *full* moon when the earth is between the sun and the moon and the moon has revolved through one-half of its orbit. Between new moon and full moon, *i.e.*, when the moon has revolved through one-quarter of its orbit, one-half of the moon is visible from the earth and we have what is called the " first quarter " ; whilst between the full and the new moon, when the moon has completed three-quarters of its journey round its orbit, we again see only a half-moon, and this period is known as the " last quarter."

All the moon's apparent variations in shape (the phases of the moon) are thus explained by its revolution round the earth, and it should be observed that the two horns of the moon (*cusps*) point in opposite directions before and after the two successive half moons. Also, we know that the moon rises later every night and that also is explained by the revolution of the moon round the earth as shown in Fig. 1.

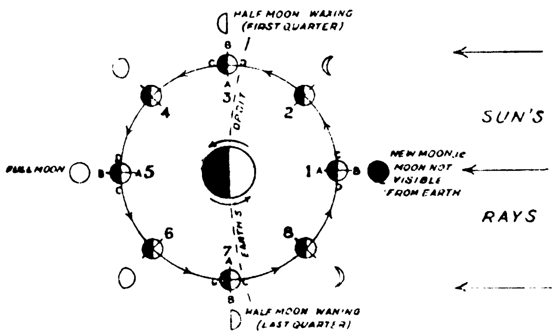
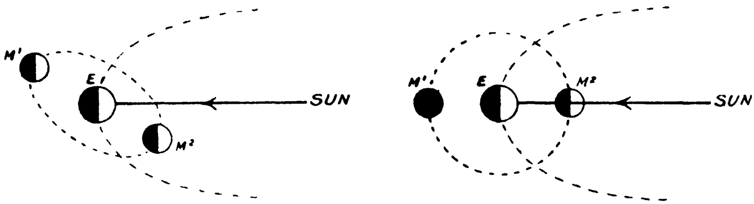


FIG. 1: REVOLUTION OF THE MOON ROUND THE EARTH.

It would appear from Fig. 1 that the moon's orbit is in the same plane as the earth's orbit round the sun. A little consideration will show, however, that this cannot be the case, for, if it were so, then at every new moon the shadow of the moon would be cast over the earth and at every full moon the shadow of the earth would be cast over the moon, *i.e.*, we should have solar and lunar *eclipses* occurring alternately about once every fortnight. Actually, the plane of the moon's orbit is "tilted" relative to the plane of the earth's orbit, so that, when the moon is between the earth and the sun, the moon is on one side of the plane of the earth's orbit, and when the earth is between the moon and the sun, the moon is on the other side of that plane. This will be clear from an examination of Fig. 2A.

At times, however, it happens that the new moon passes *exactly between the earth and the sun*, and then the shadow of the moon sweeps



PLANE OF THE MOON'S ORBIT.

FIG. 2A: NO ECLIPSE, as Sun, Moon and Earth are not in the same plane or in the same straight line.

FIG. 2B: ECLIPSES—Sun, Moon and Earth in the same plane and in the same straight line. A *Lunar* Eclipse occurs in position M¹ and a *Solar* Eclipse in position M².

across the earth and causes what is known as a *solar eclipse* (Figs. 2B and 3).

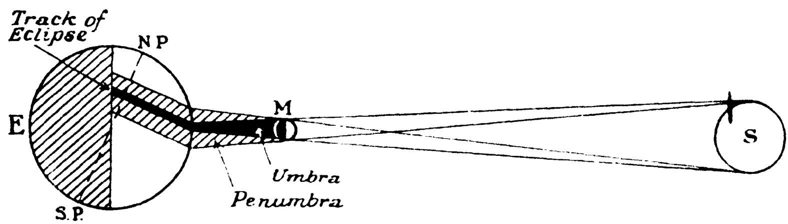


FIG. 3: SOLAR ECLIPSE.

When the moon totally obscures the sun from the point of view of an observer, no direct rays reach him. He is standing within a cone of complete shadow called the *umbra*, and is witnessing a complete eclipse of the sun by the moon. It is clear from Fig. 3 that this umbra or shadow must be cone shaped, because the sun is much greater than the moon, which therefore completely cuts off the apex of a cone of light from the sun. Just outside the umbra, the observer sees only part of the sun, and he is therefore in partial shade, which gets lighter as he sees more and more of the sun's disc. This region of semi-darkness is called the *penumbra*, and anyone standing within the ring of shadow formed by it on the earth will witness what is known as a *partial* eclipse of the sun.

When the full moon passes *behind the earth*, as viewed from the sun, the earth, being exactly between the moon and the sun, throws its

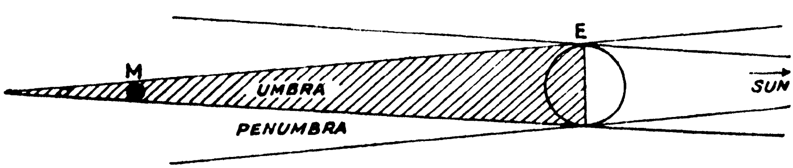


FIG. 4: LUNAR ECLIPSE.

shadow over the moon and causes a *lunar eclipse* (Figs. 2B and 4). If only part of the moon passes through the umbra of the earth's shadow, we see a *partial* eclipse of the moon.

The Earth

The earth is an oblate spheroid, *i.e.*, a sphere that has been somewhat flattened at two opposite places. The centres of these two flattened surfaces are called the *North Pole* and the *South Pole* respectively, and through them passes the imaginary axis on which the earth rotates once in twenty-four hours. The diameter of the earth from the North Pole to the South Pole is 7,900 miles, as compared with a diameter of 7,926·7 miles at the *Equator*, an imaginary line running round the earth halfway between the two Poles, so that the distortion from a perfect globe is comparatively small. The area of the earth's surface is about 197,000,000 square miles, and its circumference about 25,000 miles.

That part of the earth lying north of the Equator is called the *Northern Hemisphere*, and that part lying south of the Equator is known as the *Southern Hemisphere*.

The circumference of the earth can be determined by the method used by a Greek astronomer named Eratosthenes as long ago as 200 B.C. Eratosthenes noticed that at a certain place, which we will call *A*, the sun was vertically overhead at noon on the day of the summer solstice, whilst at a place *B*, some distance due north of *A*, the sun at the same period was 7° from the vertical. Eratosthenes, in common with all the early astronomers, regarded the earth as a sphere, and he argued that if an angle of 7° was made by the distance (D) between *A* and *B*, the

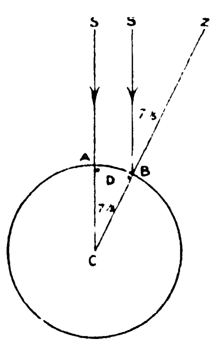


FIG. 5: MEASUREMENT OF THE EARTH'S CIRCUMFERENCE.

distance represented by 1° would be $\frac{D}{7}$, and the distance represented by 360°, *i.e.*, the total number of degrees in a sphere, would be $\frac{D \times 360}{7}$, which would equal the circumference of the earth. For example,

if D is 480 miles, the circumference of the earth would be $\frac{480 \times 360}{7}$, which is nearly 25,000 miles. Eratosthenes did not actually arrive at this figure, but the principle on which he based his calculations was employed in all succeeding attempts to determine the circumference of the earth.

How we Know the Earth is Round

The fact that the earth is spherical in shape has been deduced from the observations of various phenomena. If the earth were flat, then as soon as the sun rose above the *horizon* (*i.e.*, the line where the earth and sky appear to meet), the whole of the earth's surface would immediately receive daylight. Actually, however, places to the east receive daylight before places to the west, showing that the earth cannot be a flat body.

Again, when we are on holiday at the seaside, we frequently see ships coming into view and disappearing over the horizon. But the ships do not come completely into view at once nor does the whole of a ship suddenly disappear. On the contrary, we see first the wireless mast or the sails or funnels, and gradually the hull comes into view. In the same way, it is possible to see the higher parts of a ship long after the hull has disappeared from sight. This shows again that the earth's surface is not flat, for, if it were, the whole of the ship would come into view, or disappear as the case might be, at the same time. Moreover, a ship could be kept in view indefinitely by the aid of a sufficiently powerful telescope. As a matter of fact a ship disappears just as quickly from the view of a telescope as it does from that of the naked eye on a clear day, and the telescope only makes the apparent sinking of the ship beyond the horizon more clearly obvious.

In addition to such everyday evidence, the observation of lunar eclipses shows that the shadow thrown by the earth on the moon is always circular. The only rotating body that can continuously throw such a shadow is a sphere. A disc, for example, would at intervals throw a straight line shadow. Also, since we know that the various bodies which constitute the stellar system are all spherical in shape, there is no reason to assume that the earth does not also conform to this "globular rule".

The most convincing proof that the earth is a sphere is Wallace's experiment. Dr. Wallace erected three poles at distances of one mile apart along a straight stretch of canal, the top of each pole being at the same height above the level of the canal. A line joining the three poles would therefore be parallel to the surface of the water in the canal and, on a flat surface, if pole *C* be sighted from pole *A* through a telescope, pole *B* would coincide exactly with pole *C*. Actually, however, it was

found that pole *B* was higher than pole *A* or *C* by about 8 inches (Fig. 5A). Further, in whatever direction the experiments are carried out the results are the same. Thus a water surface must be of the same curvature in all directions at any place on the earth's surface and it follows that the earth is a sphere.

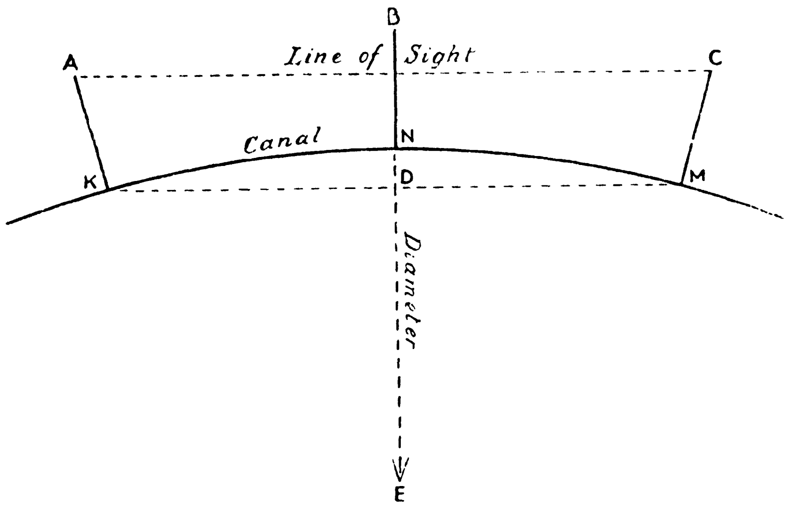


FIG. 5A: WALLACE'S EXPERIMENT.

In Fig. 5A, taking NE as diameter :—

$$ND : NK : : NK : NE$$

$$\therefore NE \text{ (diameter)} = \frac{NK^2}{ND}$$

$$\text{Now we know that } NK = 1 \text{ mile}$$

$$\text{and } ND = \tfrac{2}{3} \text{ ft. (8 ins.)} = \frac{1}{7920} \text{ of a mile}$$

$$\therefore NE = \frac{1^2}{\frac{1}{7920}} = 7920 \text{ miles.}$$

Hence, the earth is a sphere of approximately 7,920 miles diameter.

Constitution of the Earth

The constituent parts or " spheres " of the earth are shown in Fig. 6, from which it will be seen that they are four in number :—

1. THE BARYSPHERE—the hot centre of the earth.
2. THE LITHOSPHERE—the outer crust, which is very uneven and on part of which man lives, the other part being beneath—

3. THE HYDROSPHERE—consisting of the oceans and seas.
4. THE ATMOSPHERE—surrounding the land and water surface.

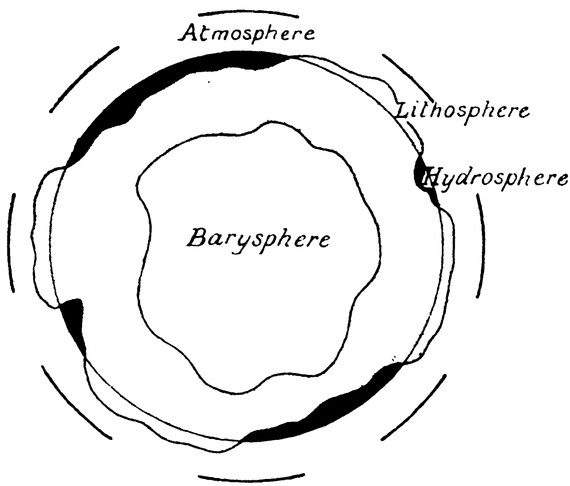


FIG. 6: CONSTITUTION OF THE EARTH.

DAY AND NIGHT AND THE SEASONS.

The earth has two movements, both of which are very important. These movements result in alternate periods of light and darkness, *i.e.*, "day" and "night", in variations in the length of day and night at different periods of the year, and in differences in the degree or intensity of light and heat received by the earth, so causing the four seasons—*Spring*, *Summer*, *Autumn* and *Winter*.

Rotation and Revolution of the Earth

Once a day (to be exact, every 23 hours 56 minutes 4·09 secs.) the earth makes a complete west to east rotation on an imaginary straight line called its *axis*, which joins the North and South Poles. This rotation is the cause of the phenomena of day and night (Fig. 7). Every day the sun appears to rise somewhere in the eastern portion of the sky and appears to set somewhere in the western portion, so that we know that the phenomena must be caused either by the revolution of the sun from east to west round a stationary earth or by the rotation of the earth from west to east while the sun remains stationary.

As has been stated, the latter is correct and has been proved by several experiments, the most important being that of Foucault's Pendulum. Many years ago Foucault hung a pendulum made of a heavy ball and a length of fine wire from a high point in a building, and set it swinging over a straight line drawn on the floor of the building. A pendulum so set should continue swinging in the same direction until

it stops, provided it is entirely free from any force which would tend to deflect it. All such deflecting forces were eliminated in this instance but it was found that the line made by the swing of the pendulum soon differed from the straight line drawn on the floor, and another line drawn

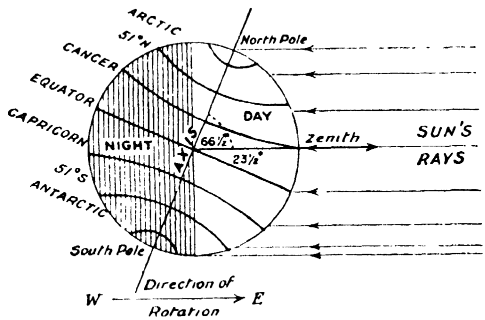


FIG. 7: DAY AND NIGHT.

on the floor in the apparent altered direction of the swing of the pendulum also soon differed from the direction of the swing. Successive lines made on the floor showed the same result, and always in the same direction. Thus it was evident that the floor, and with it the earth and everything on the earth, was continually rotating in the same direction, namely, from west to east.

At the same time as it is turning or rotating on its axis, the earth is also revolving round the sun in a path or orbit which is not quite a circle. The plane in which the path of the earth lies is called the *Plane of the Ecliptic*, so called because it is the plane in which the sun, earth and moon are all situated during either a solar or lunar eclipse. The earth's complete circuit round the sun takes approximately 365¼ days or 1 year (Fig. 8).

As our calendar year, except in leap years, has only 365 days, it is clear that we usually end one year and begin the next one-quarter of a day too soon. We should thus be one day ahead in our reckoning at the end of every fourth year if a correction were not made. For this reason "leap" years were introduced, in each of which one day is added, and which, therefore, contain 366 days. It was arranged that the leap years should be those whose number is exactly divisible by four; for example, 1904 and every 4 years thereafter. But if every year whose number was so divisible were made a leap year the correction would be excessive, for, actually, we gain something less than a quarter of a day in our calendar reckoning. A nearer approximation is ·2422 of a day. This over-correction is rectified by making the last year of every century (*e.g.*, 1900) an ordinary year of 365 days, *i.e.*, whenever the number of the year is exactly divisible by 100, *except* when the last year of the century is exactly divisible by 400. Thus the years 1800 and 1900 were not leap years but the year 2000 will be a leap year.

Length of Day and Night

We know that the alternate periods of light and darkness, or day and night, are not equal at all places on the earth's surface and that, in most places, they vary from one day to another and from one year's end to the other. These differences are accounted for by two facts :—

1. The earth's axis is not perpendicular to the plane of its orbit, *but is inclined to it at an angle of* 66½° (Figs. 7 and 8).
2. *The axis is always pointing in the same direction* (Fig. 8).

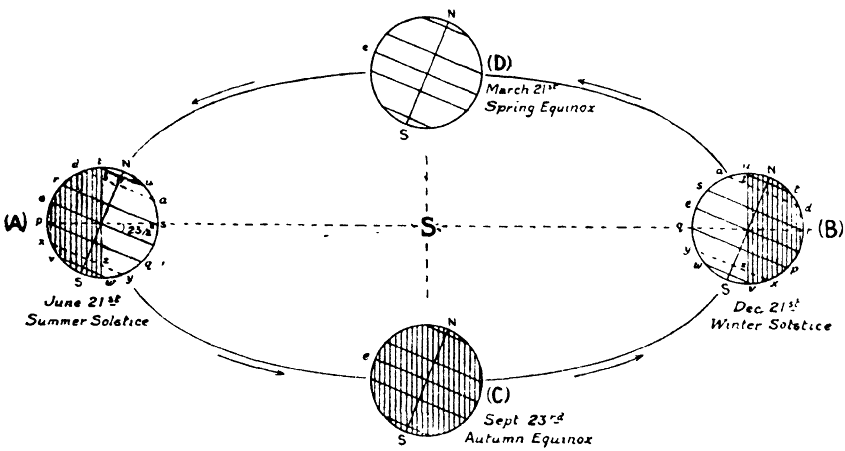


FIG. 8 : THE SEASONS.

The variations in the periods of light and darkness are illustrated in Fig. 8. The position A of the earth on June 21st clearly shows that, as a result of the inclination of the axis of the earth towards the plane of its orbit at an angle of 66½°, the area within 23½° of the North Pole receives the sun's rays continuously at this time, whilst the area within 23½° of the South Pole is in continuous darkness. These two areas are known as the Polar Regions and they lie respectively north of the *Arctic Circle* (*tu*) and south of the *Antarctic Circle* (*vw*). When the earth is in position A, all places along *ad* receive *longer periods of daylight than of darkness owing to the earth's inclination*—*la* represents the day and *dl* the night. But, for the same reason, places situated along *yx* receive a period of darkness longer than their period of light. Southwards from the Arctic Circle, therefore, the days shorten and the nights lengthen.

When the earth has completed half its journey round the sun, and is in position B, the conditions are reversed. Then, at December 21st, the area north of the Arctic Circle is in continuous darkness, whilst the area south of the Antarctic Circle is in continuous light. Also, places

along *ad* now have a short day (*al*) and a long night (*ld*), but places along *yx* have a long day (*yz*) and a short night (*zx*). Southward from the Arctic Circle, therefore, the days lengthen and the nights shorten. From these facts, and a study of Fig. 8, we can draw the following conclusions :—

1. Within the Arctic and Antarctic Circles, there is everywhere at least one day on which the sun does not set and another on which it does not rise. The number of such days increases as we approach the Poles where the period of unbroken daylight or darkness occupies half the year. (In lat. 80°, the longest period of unbroken light or darkness is about 134 days ; at lat. 70° it is 65 days ; and at the Arctic and Antarctic Circles it is 24 *hours*).

2. Over the remaining area of the earth's surface, the lengths of the periods of light and darkness into which the day is divided are always less than twenty-four hours. (In lat. 30°, the longest period of light or darkness is 14 hours ; in lat. 45° it is 15½ hours ; and in lat. 60° it is 18½ hours).

3. At the Equator, the periods of light and darkness are equal at twelve hours each throughout the year.

4. At March 21st (D in Fig. 8) and September 23rd (C in Fig. 8) *all* places on the earth's surface have exactly twelve hours daylight and twelve hours darkness, because at these times the sun is exactly overhead at the Equator. As the lengths of the day and night are equal, these periods are called the *Equinoxes*—that of March 21st being the Spring Equinox, and that of September 23rd the Autumn Equinox.

5. December 21st marks the period when the Northern Hemisphere has its maximum period of darkness and the Southern Hemisphere its maximum period of daylight. Conversely, on June 21st, the Southern Hemisphere has its maximum period of darkness, and the Northern Hemisphere its maximum period of daylight, and on the latter date, the earth is, relatively to the sun, opposite its position on December 21st.

6. Between these maximum periods, the period of daylight decreases daily and the period of darkness increases daily in the Northern Hemisphere from June 21st to December 21st, whilst in the Southern Hemisphere during the same time the days become longer and the nights shorter. From December 21st to June 21st the days lengthen and the nights become shorter in the Northern Hemisphere, and in the Southern Hemisphere the days become shorter and the nights longer.

The Seasons

If the earth's axis were perpendicular to the plane of its orbit, the sun would always be directly overhead at the Equator, and there would be no "seasons" as we know them. But the fact that the earth's axis is inclined to the plane of its orbit causes the sun to be directly overhead at different places on the earth's surface during the year. Thus, on June 21st (the *Summer Solstice*) the sun is directly overhead in the latitude of *s* (Fig. 8), and as the earth continues its journey round the sun, the inclination of the earth's axis causes the sun (as viewed by an observer on the earth at *s*) to appear to cross the sky[1] each day more and more to the south, so that, on September 23rd, the sun is directly overhead in the latitude of the Equator.

By the time the earth has completed half its revolution round the sun, *i.e.*, on December 21st (the *Winter Solstice*), the sun will have reached its position farthest south as viewed from *s* and will be directly overhead at *q*. From this time until June 21st the sun appears each day to climb higher in the sky, until on March 21st it is again overhead at the Equator. Later, on June 21st, it once more reaches its farthest north position at *s*.

Each year there is a slight variation in the precise time of occurrence of the solstices and of the equinoxes, details of which are given annually in a publication known as the *Nautical Almanac*.

In the Northern Hemisphere, the hottest part of the year, *i.e.*, the northern *Summer Season*, falls during the period from June 21st to September 23rd, after the sun has reached and is retreating from its northern limit, whilst during this period the Southern Hemisphere is experiencing its coldest months, *i.e.*, its *Winter Season*. When the sun reaches its southern limit on December 21st, the conditions are, of course, reversed, and the period December 21st to March 21st marks the southern Summer and the northern Winter. As the sun gradually moves towards its northern limit, *i.e.*, from March 21st to June 21st, it is the *Spring Season* in the Northern Hemisphere and the *Autumn Season* in the Southern Hemisphere; and when the sun is moving from its position over the Equator to its southern limit, *i.e.*, from September 23rd to December 21st, it is Autumn in the Northern Hemisphere and Spring in the Southern Hemisphere.

A further study of Fig. 8 will show that the sun is never directly overhead at those places which are north of the northern "sun limit" and south of the southern "sun limit". The inclination of the earth's axis at an angle of 66½° to the plane of its orbit naturally fixes these limits at 23½° north and 23½° south of the Equator, and imaginary lines

[1]The sun does not, of course, actually move. It is the rotation of the earth on its axis which makes it appear as though the sun were moving from east to west, and likewise it is the revolution of the earth around its orbit which makes the sun appear to climb higher in the sky.

drawn round the earth at this distance on each side of and parallel to the Equator are known respectively as the *Tropic of Cancer* in the Northern Hemisphere and the *Tropic of Capricorn* in the Southern Hemisphere (*sr* and *qp* in Fig. 8—*see* also Fig. 10). The area of the earth's surface between these two limits is known as the " Tropics ".

The Path of the Sun

As the rotation of the earth causes places to the east to see the sun before places to the west, we say that the sun *rises in the east* and, pursuing its path across the sky, *sets in the west.* Actually, the sun rises due east and sets due west only twice during each year, *i.e.*, on 23rd September and 21st March, when the sun is directly over the Equator. At other times it rises to the north or south of east and sets to the north or south of west.

In the spring and summer seasons of the *Northern* Hemisphere, when the sun is moving to its farthest north position over the Tropic of Cancer and back to the Equator, the sun rises to the north of east and sets to the north of west. Thus, during the period from 21st March to 21st June, the sun rises and sets more to the north each day, its path being from north-east through east to south and thence through west to set in the north-west. In the Northern Hemisphere, the arc of the sun's path is therefore increasing during this period and it reaches its maximum when the sun is over the Tropic of Cancer, *i.e.*, on 21st June (Fig. 9), which is the longest day in the Northern Hemisphere and the shortest day in the Southern Hemisphere. After this date, when the sun begins to move back towards the Equator, it rises and sets more to the south each day (but still north of the Equator) and in the Northern Hemisphere the arc of the sun's path becomes smaller.

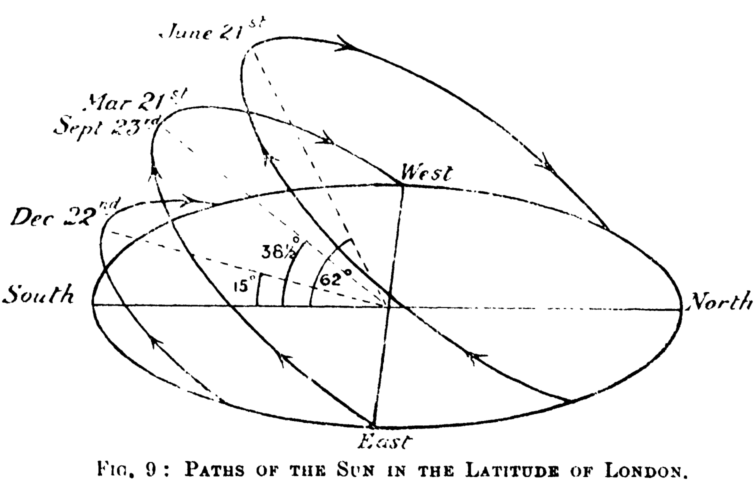


FIG. 9 : PATHS OF THE SUN IN THE LATITUDE OF LONDON.

By 23rd September, the sun is directly overhead at the Equator and from this date, as it moves towards its farthest south position over the Tropic of Capricorn in the Southern Hemisphere on 21st December and back to the Equator on 21st March, it rises to the south of east and sets to the south of west. Thus, during the autumn and winter seasons in the Northern Hemisphere the sun gives a short day to places in that hemisphere because its arc through the sky is smaller, the smallest arc being on the shortest day, *i.e.*, 21st December (Fig. 9), when the sun is over Capricorn. After the shortest day, the arc becomes bigger to places in the Northern Hemisphere as the sun moves towards the Equator, rising nearer due east and setting nearer due west each day but still rising and setting south of the Equator.

In the Southern Hemisphere, conditions are reversed, for there the path of the sun is greater between 23rd September and 21st March, but smaller between 21st March and 23rd September.

At the Equator, the path of the sun is a vertical half-circle from east to west (Fig. 9A), but between 21st March and 21st June it daily reaches a less height in the sky until on 21st June its greatest height is $66\frac{1}{2}°$ above the north horizon, *i.e.*, when it is shining directly over the Tropic of Cancer. From then until the 23rd September, the sun moves south, gradually reaching a higher point in the sky until on 23rd September it is again over the Equator and completes a half-circle from east to west. It then begins its southward movement,

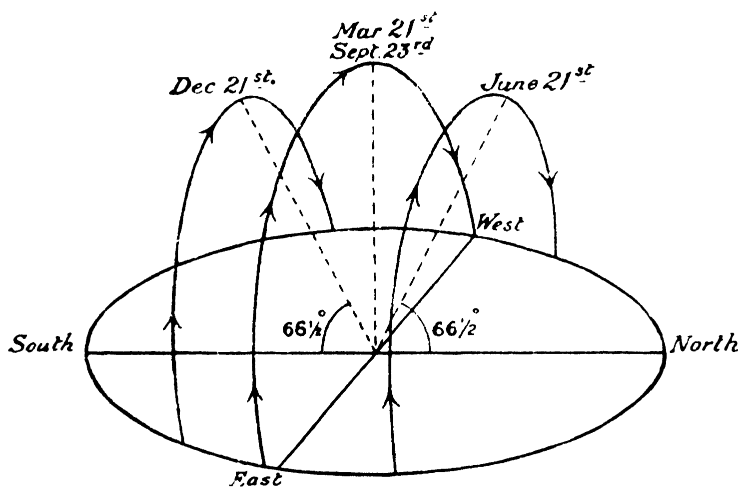


FIG. 9A: PATHS OF THE SUN AT THE EQUATOR.

rising and setting more to the south of east and west each day, its arc gradually becoming smaller until it reaches the Tropic of Capricorn at 21st December, when its greatest height is again $66\frac{1}{2}°$, this time from the southern horizon. Finally, it moves back once more to

the Equator, its height and consequently its arc becoming greater each day until it reaches its zenith over the Equator on 21st March.

At the Poles the sun does not rise and set daily but half-yearly (Fig. 9B). At the equinoxes, when the sun is directly over the Equator, the sun is circling around the horizon at the Poles. After the spring equinox, the sun gradually rises higher above the horizon, until on midsummer's day it is circling round $23\frac{1}{2}°$ above the horizon. It then begins to get lower in the sky until it is again only just on the

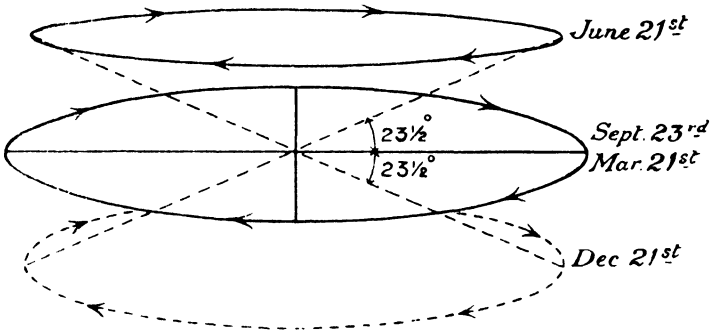


FIG. 9B : PATHS OF THE SUN AT THE NORTH POLE.

horizon. During all this time it has been continuous daylight, but after the autumn equinox the sun disappears below the horizon and is not seen again for six months, at the end of which time it again shines directly over the Equator and the period of six months daylight begins once more.

LATITUDE, LONGITUDE AND TIME

As a rule, when we are on land we have a good general idea of our position, not only in relation to our immediate surroundings, but also in relation to other places many miles away. But a lone traveller in the middle of an ocean, or in an uninhabited and totally unknown land, would find it almost impossible to ascertain his precise position unless he were acquainted with the methods which geographical science provides for the purpose. These methods involve the use of the universally accepted measurements known as " latitude " and " longitude ".

Latitude

If we journeyed in a straight line from the Equator northwards to the North Pole, or southwards to the South Pole, we should cover one-quarter of a circle round the earth. And as any circle can be divided into 360 degrees (360°), we should cover in our journey an arc of 90°. In other words, we could measure the distance over which we travelled from the Equator to the North Pole or the South Pole as $\frac{90}{360}$ of the earth's circumference, *i.e.*, 6,250 miles. This, in fact, is the method adopted for measuring distances on the earth's surface north or south of the Equator.

To facilitate this measurement, the earth is regarded as being divided up by imaginary circles drawn round the sphere on each side of the Equator and parallel to it. These lines are called "parallels of latitude", and, if the parallels are drawn to mark each degree, then the distance between each pair of parallels represents $\frac{1}{360}$ of the earth's circumference through the Poles, or approximately 69 miles.

The parallels can, of course, be placed as widely apart or as close together as is desired, at intervals of either 10° or 1° or even less, as, for example, at intervals of one "minute" (1′), *i.e.*, one-sixtieth of a degree, or even of one "second" (1″), *i.e.*, one-sixtieth of a minute or one-three-thousand-six-hundredth of a degree. For most purposes, however, intervals of 1° are sufficiently close, and on maps the intervals vary from 1° upwards. In Fig. 10 the Equator and certain other parallels of latitude are shown.

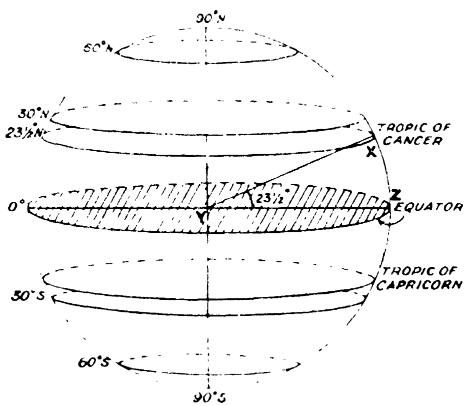


FIG. 10 : PARALLELS OF LATITUDE.

For convenience, degrees of latitude are always counted northward or southward from the Equator. The Equator is 0°, and each place north or south of the Equator is so many degrees N. or S., *e.g.*, Stoke-on-Trent (Staffordshire) is in latitude 53°N. ("N." because it is in the Northern Hemisphere), and Porto Alegro (South America) is in latitude 30°S. ("S." because it is in the Southern Hemisphere). The North Pole is latitude 90°N. and the South Pole is latitude 90°S., so that *no place can have a higher latitude than 90° either N. or S.* Places on the Tropic of Cancer are situated in latitude 23½°N., whilst places on the Tropic of Capricorn are in latitude 23½°S. It will be seen from Fig. 10 that the angle XYZ is 23½° and therefore the point X and all other points on the same parallel of latitude lie 23½°N. of the Equator.

We may say, therefore, that *Latitude is angular distance north or south of the Equator* and that there are 180 degrees of latitude over the surface of the earth—90° north and 90° south of the Equator.

Longitude

Clearly, we cannot fix the position of a place on the surface of the spherical earth merely by knowing or ascertaining its position on a circle parallel to and north or south of the Equator. We must, in addition, determine its position on the circle by measuring its distance east or west of some arbitrarily fixed point. For this purpose, use is made of the fact that there are 360° in the circumference of a circle, and the circumference of the earth at the Equator is regarded as being divided into two sections, of 180° each, east and west of an arbitrary line drawn from the North Pole to the South Pole. Starting from the point at which this imaginary line (called the zero or 0° line) cuts the Equator, the latter is divided into equal distances representing 1° and through each of the points so marked off other imaginary lines are drawn to each of the Poles. These lines are called " meridians of longitude ", and all of them are, of course, halves of circles round the earth.

Any one of these lines could be taken as the starting point and called 0°, but the meridian most generally adopted for this purpose is that on which Greenwich (England) stands, and which is known as the *Greenwich meridian*. Moreover, as in the case of parallels of latitude, we can imagine the meridians at any convenient distance apart.

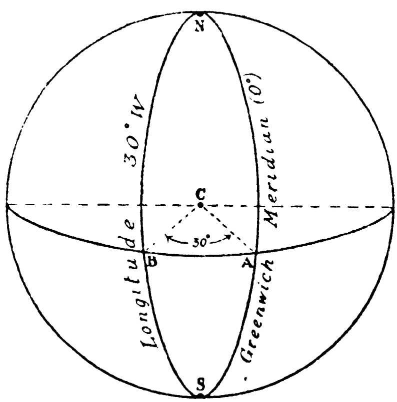


FIG. 10A: LONGITUDE.

The meridian exactly opposite Greenwich on the other side of the earth is, of course, both 180° east and 180° west from the Greenwich meridian. It is obvious, therefore, that *no place can have a greater longitude than* 180° *either E. or W.*, although the total number of meridians is 360.

In Fig. 10A let NAS be the Greenwich meridian (0°); C, the centre of the earth; EAB, the Equator. Then, if the angle BCA is 30°, the line NBS is longitude 30°W.

Longitude is therefore angular distance east or west of the Greenwich meridian, measured in degrees, minutes and seconds.

Although degrees of longitude can be divided, as angles, into minutes and seconds in a similar manner to degrees of latitude, the *linear* distance between meridians decreases as distance from the Equator increases, whereas the linear distance between each degree parallel of latitude is everywhere approximately the same. That this cannot be otherwise is apparent when we recall that all meridians meet at the Poles. Thus, at the Equator, the distance between each meridian is about 69 miles, the same as a degree of latitude, but at the parallel of latitude which passes through London the meridians of longitude are only 43 miles apart, while at the Arctic Circle they are only 28 miles apart. These facts are clearly demonstrated in Fig. 11, which shows parallels and meridians as viewed from the North Pole.

It should now be clear that we can easily determine the exact position of a place on the earth's surface if we know or can determine *both* its

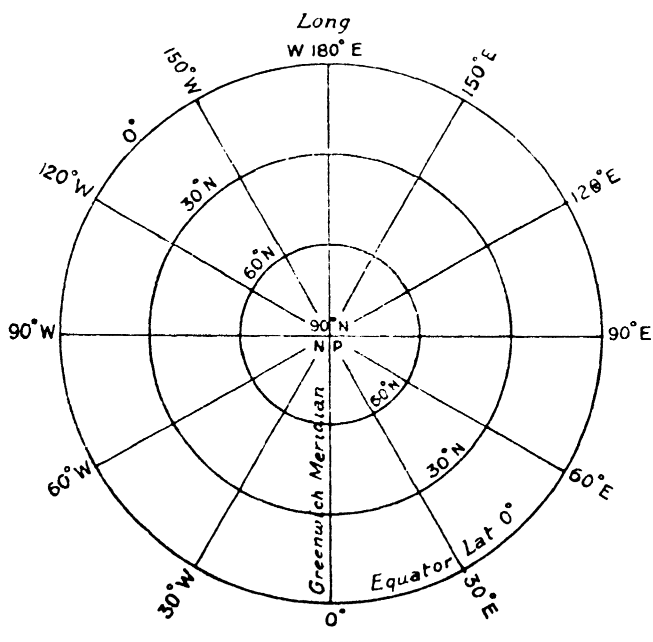


FIG. 11: LATITUDE AND LONGITUDE FROM THE NORTH POLE.

latitude and its longitude. Thus, in Fig. 12, place *a* is situated in lat. 30°S., long. 70°E., *i.e.*, it lies 30° south of the Equator and 70° east of the Greenwich meridian; place *b* is situated in lat. 50°N., long. 10°W., *i.e.*,

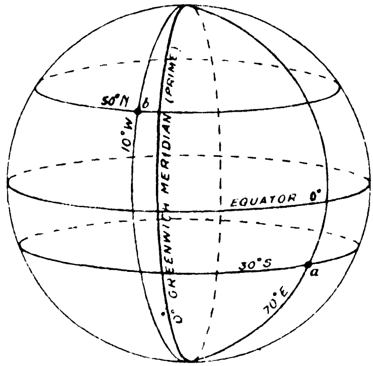


FIG. 12: POSITION AS INDICATED BY LATITUDE AND LONGITUDE.

it is situated where the imaginary parallel of latitude 50° north of the Equator cuts the imaginary meridian 10° west of Greenwich.

How Latitude is Determined

The most convenient method of determining the latitude of a place, and the one most used in the Northern Hemisphere at night, is that of observing and measuring the mean altitude in angular degrees of the Pole Star above the horizon. This measurement gives the latitude of the place sufficiently accurately for all practical purposes.

The Pole Star is a bright star which is directly overhead, *i.e.*, in the *Zenith*[1], at the North Pole, and it may be found by first looking for the constellation called the " Great Bear " or " Plough ", the two end stars of which are always in a direct line with the Pole Star. The Pole Star may also be found by the use of a compass.

At the Equator, the Pole Star appears directly on the horizon, and it is found that, for every degree of latitude the observer advances north of the Equator, the Pole Star appears one degree higher above the horizon, until at the Pole it is at an angular altitude of 90°, or directly above the observer. Thus at places situated in 1°N. latitude, the Pole Star is seen 1° above the horizon ; at 2° N. latitude, the Star is 2°

[1]The *Zenith* of a place is the point in the sky which is immediately overhead, *i.e.*, which is at an altitude of 90° from the horizontal, at that place. The *Nadir* is the point in the celestial sphere or sky opposite to the Zenith, *i.e.*, it is the point directly beneath the observer's feet.

above the horizon ; and so on. The matter is more generally explained as follows :—

In Fig. 13 let P be the point the latitude of which is required, E a point on the Equator, N the North Pole and C the centre of the Earth. PH is the horizon plane through P, and is, of course, at right angles to APC, the line joining P to the centre of the earth. The Pole Star is then

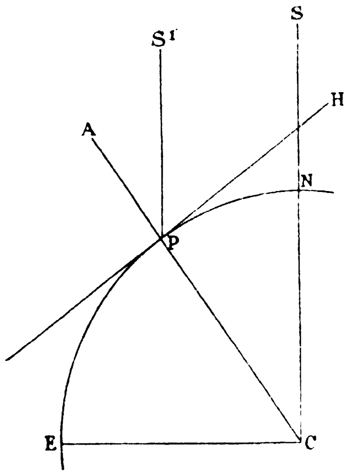


FIG. 13 : MEASURING LATITUDE BY THE POLE STAR.

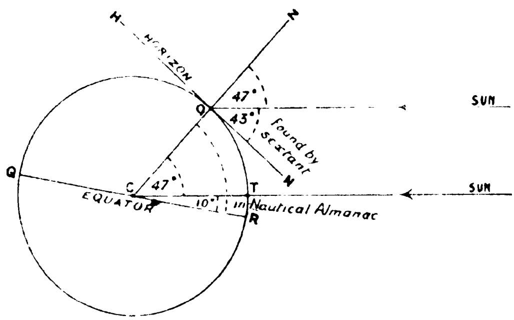


FIG. 13A : DETERMINATION OF LATITUDE BY DAY.

situated on the line CS. An observer at P will look at the Pole Star in a direction PS′, which is virtually parallel to CS owing to the great distance of the star.

The angle ECP is the measure of the latitude of P.

$$\text{Now } \angle\ ECP = 90^\circ - \angle\ NCP$$
$$\text{And } \angle\ HPS' = 90^\circ - \angle\ S'PA$$
$$\text{But } \angle\ NCP = \angle\ S'PA$$
$$\therefore \angle\ HPS' = \angle\ ECP.$$

∴ The latitude of P is the angle HPS′, *i.e.*, the angle of elevation of the Pole Star above the horizon.

In the Southern Hemisphere the Pole Star is, of course, invisible and latitude is there determined by means of the group of stars known as the Southern Cross, but the calculation is not so simple because there is no one star directly above the South Pole.

Determination of Latitude during Daytime.

During the day-time at sea, latitude is found by measuring the angle between the sun and the horizon at noon by means of an instrument

called a " sextant ", and then referring to the ship's copy of the *Nautical Almanac*, in which there are tables to enable the latitude to be found from the result of the observation made with the sextant.

Let us suppose that the altitude of the mid-day sun has been found to be 43°. Also let us suppose that by reference to the *Nautical Almanac* the angular distance of the sun from the Equator on the date in question has been found to be 10°N. The latitude of the ship is therefore 57°N.

This should be clear from Fig. 13A.

The circle represents the earth. C is the earth's centre and O the position of the observer. The horizon plane HN is drawn at right-angles to COZ. OS is the direction of the sun.

$\therefore \angle$ SON = Sun's altitude = 43° (found by sextant).
$\therefore \angle$ ZOS = 47°

and since all rays from the sun to the earth are parallel,
$\angle$ ZOS = $\angle$ ZCT = 47°.

Now T represents the position on the earth where the sun is vertical and, by reference to the *Nautical Almanac*, this place is given as 10°N. of the Equator, $\therefore \angle$ TCR = 10°

$\therefore \angle$ OCR = 47° + 10° = 57°
and, by definition, $\angle$ OCR is the latitude.

The student can work out many variants with, say, overhead sun south of the Equator, and the observer in the Southern Hemisphere, and so on.

Longitude and Time

Longitude is determined by comparing local time with Greenwich time kept by the use of a " chronometer ", a very accurate watch set to Greenwich time, which is obtainable all over the world either from clocks set to it or by wireless. The difference between these times enables the observer to calculate his position east or west of the Greenwich meridian in the following way.

As the earth rotates on its own axis once in every 24 hours, every imaginary line of longitude faces the sun directly once every day, and when a place is directly facing the sun, *i.e.*, when the sun is highest in the heavens, the time at that place is called " noon ", or " 12 o'clock noon ", or " midday ". Thus, *all places situated on the same meridian of longitude must have their local noon at the same time.* (N.B.—*Meridian* = mid-day.)

As the earth revolves through 360° of longitude in 24 hours, it follows that it turns through $\frac{360°}{24}$ or 15° in 1 hour, and $\frac{15°}{60}$ or $\frac{1}{4}$° in 1 minute, *i.e.*, it turns 1° in 4 minutes. Consequently, for every degree of longitude there is a difference of 4 minutes in time according to the sun.

Since the earth rotates from *west to east*, places *east* of the Greenwich meridian will see the sun *before* places in the same longitude as Greenwich, and places *west* of the Greenwich meridian will not see the sun until *after* places on that meridian. We therefore have the following very important rule: *For places east of Greenwich, time is in advance of Greenwich time; and for places west of Greenwich, time is behind Greenwich time.* We can put this in another way by saying that, compared with Greenwich time, the time at places situated *east* of Greenwich is *fast*, whilst the time at places situated *west* of Greenwich is *slow*.

How Longitude and Local Time are Determined

The above facts enable us to find the longitude of any given place if we know the time thereat *and* the time at Greenwich; or, if we know the longitude of a place *and* Greenwich mean time, to find the local time at that place. Thus, if at place A it is 11 o'clock a.m. and Greenwich time is 12 o'clock noon, the longitude of the place is 15° *west* of Greenwich, for the earth revolves through 15° in 1 hour and the time at A is *slow* compared with the time at Greenwich.

Then suppose it is noon at a place B, and that the chronometer shows that it is 9.40 a.m. at Greenwich. We know then that the longitude of B is 35° east, for there is a difference in time between the two places of 2 hours 20 minutes, or 140 minutes, and, as a difference of 4 minutes represents 1° of longitude, the place is situated in $\frac{140°}{4}$ = 35° from Greenwich, and it must be *east* of Greenwich, because the time is *fast* compared with the time at Greenwich.

St. John (New Brunswick) is situated in long. 66° 2′ W., so that when it is 8 a.m. at Greenwich, the time at St. John will be 8 a.m. *minus* $66\frac{1}{30} \times 4$ minutes = 8 hours − 4 hours 24 minutes 8 seconds = 3 hours 35 minutes 52 seconds, or roughly 24 minutes to 4 in the morning. It should be observed that the time difference has to be *deducted*, as St. John is *west* of Greenwich.

Again, when it is noon at Greenwich, the time at Cracow (Poland), situated in long. 20°E., will be 20 × 4 minutes = 1 hour 20 minutes *after* noon, *i.e.*, 1.20 p.m. Here the time difference has to be *added*, because Cracow is *east* of Greenwich.

It should now be clear why, for example, we receive the closing Test Match scores from Australia on the morning of the day on which the match is actually played in Australia. In these matches play finishes at 6 *p.m.*, yet the scores are known in London about 8.30 *a.m.* of *the same*

day. This time difference is, of course, due to the distance of, say, Melbourne from London and the Greenwich meridian. Melbourne is in long. 145°E., therefore the actual time difference by the sun is 145 × 4 minutes. This has to be *added* to Greenwich time as Melbourne lies *east* of Greenwich, so that when it is 8.30 a.m. at Greenwich it is 6.10 p.m. of the same day in Melbourne.

Standard Time

It will be realised that the frequent differences in local (or " sun ") times between places situated in various parts of the great continents of the world might well lead to much confusion. This will be appreciated more readily when it is realised that, even in a small area such as Southern England, there is a difference from east to west of nearly 30 minutes in times according to the sun, *i.e.*, in local time. For purposes of convenience, therefore, the world is divided into standard " time-belts " or " time-zones ", whereby places in the same neighbourhood observe the noon of one fixed place, *i.e.*, they adopt what is known as *Standard Time* (Fig. 14).

In several of the Western European countries, such as France, Belgium, Spain and Portugal, Greenwich time is the " standard " time ; in Sweden, Norway, Denmark and the countries of Central Europe, the standard time is one hour fast of Greenwich time, *i.e.*, time is taken from the meridian 15°E. ; in Eastern Europe, time is taken from long. 30°E., *i.e.*, two hours fast of Greenwich. The whole of India, except Calcutta, is 5½ hours fast of Greenwich, whilst in Australia there are three standard time-belts—one 10 hours ahead of Greenwich for the States of Victoria, New South Wales, Queensland and Tasmania ; another 9½ hours ahead of Greenwich for the States of Northern Territory and South Australia ; and the third 8 hours ahead of Greenwich for the State of Western Australia. America is similarly divided into time-belts. For example, Canada has five time belts with one hour's difference between successive belts. The belts are based on the local time of the meridians 60°W., 75°W., 90°W., 105°W. and 120°W. Thus, the Atlantic time belt includes the area between long. 68°W. and the east coast and adopts as its standard time the local time of long. 60°W., *i.e.*, 4 hours slow on Greenwich. Between longs. 68°W. and 90°W. (the Eastern time belt), the local time on the meridian 75°W. is the standard time, *viz.*, 5 hours slow on Greenwich ; between longs. 90°W. and 102°W. is the Central time belt, which uses as standard time the local time of long. 90°W., *i.e.*, 6 hours slow on Greenwich ; the Mountain time belt from long. 102°W. to the eastern boundary of British Columbia takes its standard time from long. 105°W. or 7 hours slow on Greenwich ; and British Columbia bases its standard time on the 120°W. meridian, *i.e.*, 8 hours slow on Greenwich. Thus, for each time zone westward the standard time is one hour slower, *e.g.*, when it is noon at Halifax in the Atlantic belt, it is 11 a.m. according

to *standard* time at Toronto in the Eastern belt, 10 a.m. at Winnipeg in the Central belt, 9 a.m. at Calgary in the Mountain belt, and 8 a.m. at Vancouver in the Pacific belt.

The International Date Line

When it is noon on, say, Tuesday at Greenwich, the time at a place 180°E. is midnight between Tuesday and Wednesday, whilst the time at the same place reckoned as 180°W. is midnight between Monday and Tuesday. In other words, it is Tuesday morning in the immediate west of the 180° meridian and Tuesday evening in the immediate east of that meridian. As soon, therefore, as the instant of midnight has passed, a person could step across the 180th meridian westward and pass from Tuesday morning to Wednesday morning, or he could step across eastward and pass from Wednesday morning back to Tuesday morning. At, say, four minutes past noon, Greenwich time, it is four minutes past midnight at the 180th meridian. Hence, between 180° and 179°E. longitude, the date is Wednesday and for the rest of the world it is Tuesday.

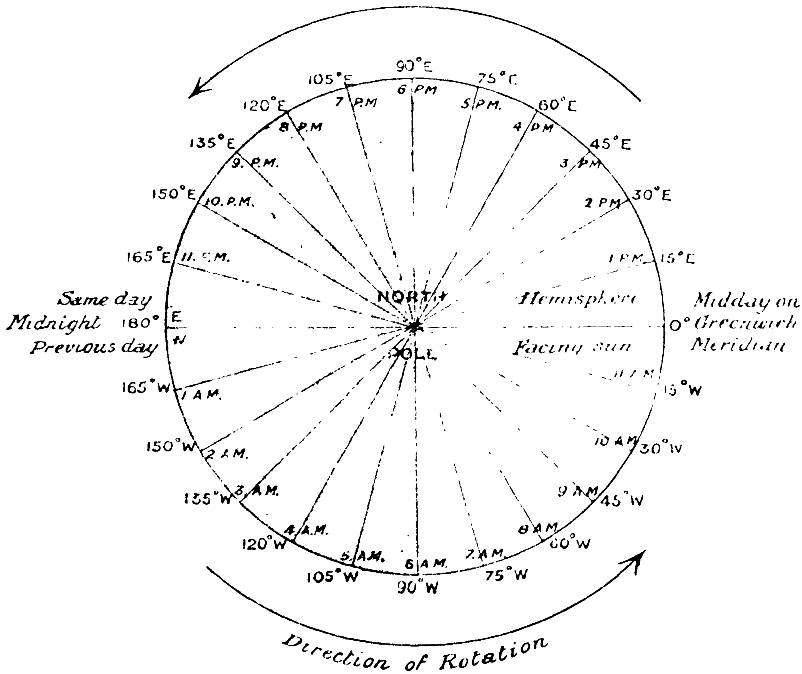


FIG. 14 : LONGITUDE AND TIME.

As it grows later at Greenwich, Wednesday spreads round the earth, until at, say, four minutes to noon, Greenwich time, Tuesday is confined to the arc 179° to 180°W. longitude. As noon on Wednesday (Greenwich

time) passes, Tuesday disappears at 180°W., and Thursday begins at 180°E. and in its turn spreads round the earth.

It should now be clear that whenever we cross the 180th meridian we pass from one day to another. As this would be awkward on land, where people might move to and fro very often, a special date line has been defined by international convention. It is called the *International Date Line*, and follows the 180° meridian as closely as possible through the Pacific ocean without touching land.

Whenever ships cross this date line they have to adjust their logs. If they are sailing *westward*, they miss 24 hours and pass to the next day : if they are sailing *eastward*, they pass to the previous day ; for example, from 9 o'clock Wednesday to 9 o'clock Thursday going westward, or from 9 o'clock Thursday to 9 o'clock Wednesday going eastward.

Great Circles and Great Circle Sailing

Of the circles that can be drawn on the earth the greatest are those whose plane passes through the centre of the earth. These are called *great circles*, and, as the earth is nearly spherical, they are approximately equal in length. Great circles include the Equator, the meridians and any other circle whose circumference is equal to the circumference of the earth (see Fig. 14A).

All other circles drawn on the earth are called *small circles*. Of these the parallels of latitude (excluding the Equator) are the most notable ; obviously their planes cannot pass through the earth's centre (Fig. 14B).

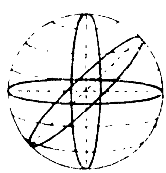


FIG 14A: GREAT CIRCLES.

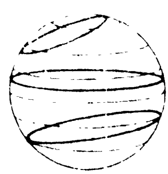


FIG. 14B: SMALL CIRCLES.

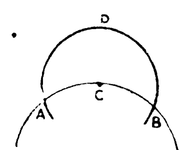


FIG. 14C: GREAT AND SMALL CIRCLES THROUGH AB. ACB IS A SHORTER DISTANCE THAN ADB.

The rate of curvature of a small circle is quicker than that of a great circle, and, if through two points on the earth's surface a great and small circle each be drawn, the length of the arc intercepted between the two points will be greater in the case of the small circle than of the great circle. Fig. 14C shows that to be so.

The fact that the shortest distance between two points on the earth's surface is along the great circle passing through them is made use of by mariners and by pilots of aircraft. Instead of following the parallel of latitude between the two points, they follow the great circle passing through the two places. (See Chapter 20.)

QUESTIONS ON CHAPTER 2

1. What is meant by the longitude of a place ? How do sailors determine their longitude when at sea ? Has wireless telegraphy enabled them to do this more accurately ? If so, how ? When it is 10.30 a.m. at Greenwich what is the local time at New York 74°W., at Karachi 67°E., at Vancouver 126°W. ? (*S.A.A. Prelim., May*, 1930)

2. When Greenwich time is 12 noon, give (approx.) the local time of the following places: New York, Calcutta, Melbourne, Buenos Aires. Explain the use of time-zones, giving examples from Europe and North America. (*C.I.I. Prelim.*, 1931)

3. State how the length of day (and night) changes during the year at the Tropic of Cancer, London, the Arctic Circle, and the North Pole. (*C.I.I. Prelim.*, 1930)

4. (*a*) Explain, with the help of diagrams, how lines of latitude and longitude are drawn on a globe.
   (*b*) State why it is necessary to know both the latitude and longitude of a place in order to find its exact position on a globe.
   (*c*) Describe the position of the North Pole as regards latitude and longitude. (*C.S., November*, 1928)

5. When it is noon by the sun at Greenwich, what time is it by the sun at Sydney (150° East Longitude) ? Explain how you obtain your answer. (*C.S., Feb.*, 1929)

6. Describe the daily and yearly movements of the Earth and the results of those movements. (*C.S., Oct.*, 1929)

7. (i) The 6 p.m. score in a Test Match played at Melbourne (long. 145°E.) is published in the mid-day editions of the London newspapers on the same day. How is this possible ?
   (ii) Christmas-day in Melbourne occurs in the summer. Why is this ? (*C.S., March*, 1928)

8. Explain the meaning of the terms latitude and longitude.
   Why are lines of latitude and longitude drawn across maps ?
   Draw a circle (radius 2 inches) to represent a globe and on it mark the two Poles, the Equator, the Tropic of Cancer, and one meridian of longitude. Write these names on the diagram. (*C.S., March*, 1929).

9. In June and in December, the sun is overhead at the Tropics of Cancer and Capricorn respectively. Explain how this comes about and show what effect it has on the difference in (*a*) temperature, (*b*) length of daylight, between summer and winter in the British Isles. (*C.S., June*, 1931)

10. Kolinsk in Eastern Siberia, 66½N. ; 150½E.
    Rockhampton in Queensland, 23½S. ; 150½E.
    (*a*) State clearly, giving your reasons, the variation of light and darkness and the change of season at Kolinsk and Rockhampton respectively.
    (*b*) What time will it be at these places when it is noon at Greenwich ? Show clearly how you obtain your results. (*C.S., May*, 1929)

11. Describe and explain the seasonal changes in the altitude of the noonday sun at the North Pole, the Arctic Circle, and the Tropic of Cancer. (*C.S., Jan.*, 1938)

CHAPTER 3

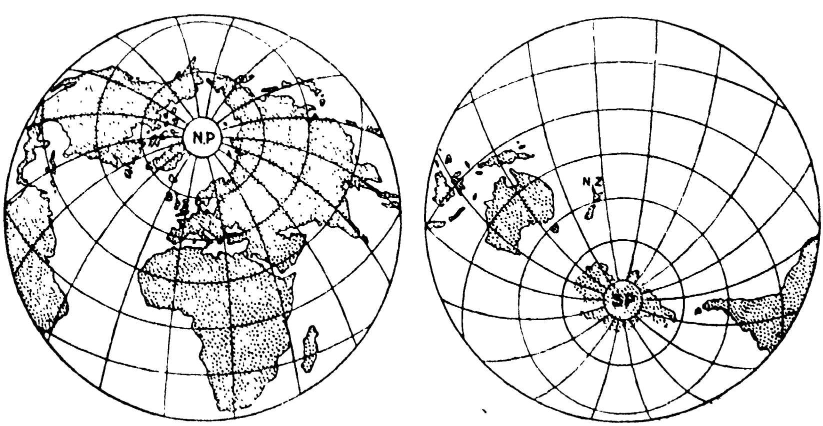
THE SURFACE OF THE EARTH

Distribution of Land and Water

MUCH more of the surface of the earth is covered by water than is covered by land, for while the hydrosphere covers an area of 141,050,000 square miles, the land surface has an area of only 55,500,000 square miles. The present distribution of land and water has been preceded by ages of gradual change, during part of which time it is likely that the whole surface of the lithosphere was covered with water. In the process of change, some parts of the lithosphere have risen whilst other parts have sunk, and as a result we have various earth forms ranging from the highest mountain to the great ocean depths. Thus the outer surface of the lithosphere is very uneven, and it is still changing through the action of earthquakes, rivers and other influences.

The highest point of the earth's surface is the top of Mount Everest in the Himalayas (about 29,000 feet), while the lowest depth of the hydrosphere is in the Pacific Ocean off Mindanao in the Philippine Islands (about 32,000 feet). Whereas the average height of the land above sea-level is only 2,300 feet, the average depth of the larger water surface exceeds 12,000 feet.

The land surface of the earth is divided into seven major regions called *continents*, and the water surface into six major divisions known as *oceans*. A map of the world will show that, speaking generally, the



LAND HEMISPHERE. FIG. 15. WATER HEMISPHERE.

continents taper towards the south and broaden towards the north, whereas the oceans taper towards the north and broaden towards the south. Another notable feature of the distribution is that most of the land surface is in the Northern Hemisphere and the greater part of the water surface in the Southern Hemisphere (Fig. 15). The British Isles lie approximately in the centre of the land hemisphere and New Zealand nearly in the centre of the water hemisphere—factors which are largely responsible for the great difference in the development of the two countries. Finally, much of the land surface is in the temperate zone.

Continents

The word " continent " is a conventional term which, in its strictest sense, means a continuous and very extensive area of land surrounded by water. Thus the seven " continents " of the earth are Europe, Asia, Africa, North America, South America, Australia and Antarctica.

Although many very large bodies of land, *e.g.*, Borneo, New Guinea, Greenland and Baffin Land, are not considered to be worthy of the name " continent ", it is evident that, even in its most restricted use, the word is applied to land masses which do not conform to its rigid definition. Europe, Asia and Africa are naturally joined together. So are North and South America. Furthermore, it is usual to include in a " continent " any islands that are intimately connected with it, *e.g.*, the British Isles are regarded as forming part of Europe in Geography, though not in Politics: Japan is included with Asia; Australia is always understood to include Tasmania.

By far the largest land mass is that which comprises the continents of Europe, Asia and Africa.

EUROPE.—The continent of Europe, with a total area of $3\frac{3}{4}$ million square miles and an estimated population of 550 millions, is situated approximately in the centre of the Land Hemisphere (Fig. 15), and contiguous to it is the continent of Asia, stretching eastward from long. 25°E to long. 170°W. These two continents are frequently referred to as the land mass of " Eurasia ". Included in the European continent are the British Isles, France, Spain, Portugal, Belgium, Holland, Denmark, Germany, Switzerland, Italy, the Baltic States, Finland, Poland, Czechoslovakia, Hungary, Rumania, the Balkan States, Norway, Sweden and European Russia. Over 50 per cent. of the surface of the continent is lowland, *i.e.*, land of 600 ft. or less above sea-level, and of all the continents, Europe has the greatest percentage of lowland and the longest coastline in proportion to its area. Less than 10 per cent. of its surface is highland, *i.e.*, land over 3,000 ft. above sea-level.

ASIA.—The continent of Asia is separated from Europe by the Ural Mountains, the Ural River, the Caspian Sea, the Caucasus Mountains, the Black Sea and the Sea of Marmara. It has a total area of 17 million

square miles and an estimated population of over 1,000 millions. The area of highland comprises nearly 40 per cent. of the whole, a higher proportion than that of any other continent, while lowland areas occupy about 23 per cent. The chief countries of the continent are India, Japan, China and Asiatic Russia.

AFRICA.—The continent of Africa, lying immediately south of Europe, and separated from it by the Mediterranean Sea, is joined to Asia by the narrow neck of land known as the Isthmus of Suez. Elsewhere it is entirely surrounded by sea and may be regarded as a huge peninsula of the Eurasian land mass. The area of the continent is 11½ million square miles, of which over 60 per cent. lies between 600 and 3,000 feet above sea-level, whilst the area of lowland is only about 12 per cent. and the highland areas occupy about 25 per cent. Almost the whole of the continent has been partitioned among the peoples of Europe and there is now no country which enjoys complete political independence. British territory includes the Anglo-Egyptian Sudan, Kenya, Tanganyika (a mandatory region), Uganda, the Union of South Africa (a Dominion of the British Empire), South-West Africa (under a mandate) and the West African Colonies. Portugal has possessions on the east and west, France and Italy in the north, east and west, and Spain in the west. Belgium exercises supremacy over a large tract of country known as the Belgian Congo. Egypt is independent, but certain rights are reserved to Britain in connection with the Suez Canal Zone. The population of Africa is estimated at 150 millions.

AUSTRALIA.—The remaining continent of the Eastern Hemisphere is that of Australia. This, with Tasmania and New Zealand, constitutes *Australasia*. Australasia and the islands of the Pacific Ocean are sometimes grouped together and called *Oceania*. Australia has an area of about 3 million square miles and a population of 7 millions. About 30 per cent. of the total area is lowland, whilst the high land occupies only about 2 per cent.—the lowest percentage of all the continents.

THE AMERICAS.—The Western Hemisphere contains the two continents of *North America* and *South America*, joined by the narrow Isthmus of Panama. These two land masses reach from well within the Arctic Circle to about lat. 56°S., whilst the extreme north-west of North America (Alaska) is separated from the north-east of Asia only by the narrow Bering Strait.

North America is divided politically into Canada, Newfoundland, the United States of America, Alaska, Mexico, the Central American Republics and British Honduras. It has a total area of 8 million square miles, of which over 30 per cent. is lowland and over 20 per cent. highland. The estimated population is 170 millions.

The whole of *South America*, except for the British, Dutch and French Guianas in the north-east, consists of independent Republics, of which the chief are Argentina, Brazil and Chile. The area of the continent

is 6·8 million square miles and the estimated population 74 millions. Lowland areas occupy about 40 per cent. of the total area, whilst about 23 per cent. consists of highland.

Islands of the World

Apart from the continents, there are numerous small tracts of land surrounded by water, called *islands*, *isles* or *islets*. They vary greatly in area, from Greenland, the largest (736,500 square miles), to those which are only just protruding from the water, and they may all be regarded as forming part of one or other of the continents. Thus, the British Isles are geographically part of the continent of Europe; the West Indies are usually included when we refer to the North American continent; Madagascar is included in Africa; the East Indies in Asia; and so on.

Islands are of two classes—*continental* and *oceanic*. Continental islands are so called because at one time they were probably part of neighbouring continents, as is indicated by the fact that their geological structure is similar to that of the "parent" land. In such cases, the water between the island and the mainland is usually very shallow, and there is, as a rule, evidence that within comparatively recent geological times the area now covered by water has sunk. A further proof that these islands were once part of the mainland is afforded by the fact that their plants and animals are of similar species. Thus, there is every reason to believe that Great Britain was at one time attached to the continent of Europe. The geological formation of the east and south coasts of England is similar in many respects to that of the mainland of the continent, whilst there is a close similarity between the plants and animals of the two regions.

Oceanic islands are usually either volcanic or coral. The latter are formed by the *coral polyp*—a sea organism which, by depositing coral formed from lime obtained from the sea water, gradually builds up, as it multiplies, a mass of coral rock, which spreads and eventually rises to the surface of the water. In the course of time, the islands become covered with vegetation. Coral islands (*e.g.*, those of the South Pacific), are usually situated at great distances from the land masses and are to be found only in the lower latitudes, for the polyp cannot live in a temperature of less than 68°F. There are three distinct classes of coral formations:—

1. FRINGING REEFS, formed in shallow water close to the shore.
2. BARRIER REEFS, formed by the erosion of fringing reefs and the gradual moving or drifting of the reef seaward. Barrier reefs usually enclose a lagoon of calm water.

3. ATOLLS, which, according to Darwin and other authorities, begin as fringing reefs, are usually circular in shape, and enclose lagoons which form natural harbours.

WATER SURFACE OF THE EARTH

The water surface of the earth—the hydrosphere—covers an area more than $2\frac{1}{2}$ times as great as that of the outer lithosphere. It differs in its distribution from the land surface in that the major portion forms one continuous belt round the earth and in that it mostly lies south of the Equator (Fig. 15).

Oceans and Seas

The hydrosphere is regarded for convenience as being divided into six *oceans* :

1. THE ATLANTIC OCEAN, lying between Europe and Africa on the east, and North and South America on the west. This is commercially the most important. Most of the large rivers of the world flow into it, but it contains comparatively few islands.
2. THE PACIFIC OCEAN, lying between the Americas on the east, and Asia on the west. It is the largest of the oceans, occupying an area greater than that of all the land of the globe. It contains numerous islands, some of which are of great importance.
3. THE INDIAN OCEAN, lying between Asia, Africa and Australia. The major portion of this ocean lies south of the Equator. Many of the great Asiatic rivers flow into it and it contains numerous important islands.
4. THE SOUTHERN OCEAN, an almost uninterrupted belt of water stretching round the globe between lat. 40°S. and lat. $66\frac{1}{2}$°S.
5. THE ARCTIC OCEAN, lying north of the Arctic Circle.
6. THE ANTARCTIC OCEAN, lying south of the Antarctic Circle.

Special parts of the oceans are identified as particular *seas*. Thus, the Atlantic Ocean includes the so-called *inland seas*—the Mediterranean Sea. the Black Sea, the North Sea, the Baltic Sea and the less definitely marked Caribbean Sea. In the Pacific Ocean are the Yellow Sea, the China Sea and the Sea of Japan.

In many--indeed, in most—parts of the world the coast line bordering the sea is considerably indented, forming bays, gulfs, inlets and fiords. A *bay*, as for example the Bay of Bengal, usually denotes a shallow indentation, and a *gulf* a more pronounced indentation, as in the case of the Gulf of Mexico, but this rule does not apply strictly, *cf.* the Gulf of Alaska and Hudson Bay. A small opening is usually termed an *inlet*, though inlets which are long, narrow and rocky are called *fiords* or *fjords* (see p. 66).

These various coastal openings, too, receive different names in different countries. Thus, in Scotland the fiords are called *lochs*, and the bays *firths*; in Ireland the term *lough* is used. A narrow stretch of water separating two pieces of land is called a *strait* or *sound*, and wider passages are termed *channels*, *e.g.*, "The Straits of Dover" and "The English Channel".

Floor of the Ocean

When a representative section of the floor of an ocean is examined we see that there are four main features (Fig. 16). As a rule, the floor slopes very gently from the coastline, forming what is known as the *continental shelf*, which descends to a depth of about 100 fathoms (600 feet). The 100 fathom limit usually marks the beginning of the *continental slope*. This is much steeper than the shelf, and descends to 2,000–3,000 fathoms. Beyond this is the *deep sea plain*, having gentle slopes and varying comparatively little in depth. The fourth

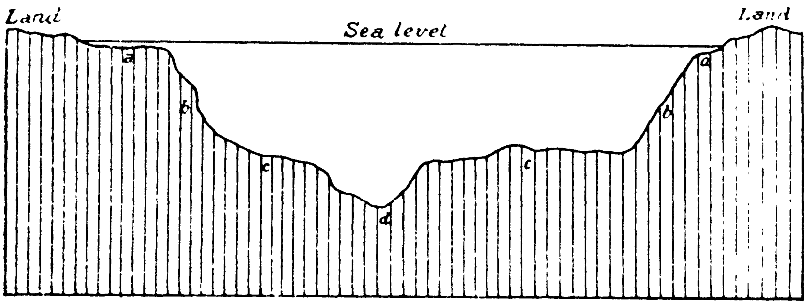


FIG. 16: SECTION ACROSS OCEAN FLOOR (NOT TO SCALE).
aa shelf: *bb* slope; *cc* plain; *d* deeps.

division consists of the *deeps*, which usually lie towards the sides of the oceans and are of relatively small area with steep sides. Every ocean exhibits these divisions, although in some they are more marked than in others. In the Atlantic Ocean, for instance, the continental shelf is strongly marked, while in parts of the Pacific Ocean it is hardly defined at all. On maps, the varying depths of the oceans are indicated by lines joining all places of equal depth. These lines are known as "*isobaths*".

COMPOSITION OF THE SEA FLOOR.—In the shallow waters of the continental shelves, the floor consists of deposits denuded by the action of rivers, rain and sea. Thus, the deposits vary with the composition of the adjacent land, but consist generally of gravel, sand and mud. Elsewhere, the floor of the ocean is covered with deposits of Red Clay and of different kinds of what is termed "ooze", the most important variety of which is *Globigerina ooze*, comprised mainly of the chalk-shells of very small animals mixed with volcanic matter. Red clay, which consists largely

of volcanic dust and the remains of shells, covers a wide area of the deepest parts of the floor of the oceans.

The Atlantic Ocean

The average depth of the Atlantic Ocean is about two miles, the greatest depth being the Porto Rico Trench, in the West Indies, which is over 4,660 fathoms. In the North Atlantic the continental shelf is well marked on both sides of the ocean. In the east, the British Isles lie on the European continental shelf. Towards the centre the deep sea plain rises gently to form a prominent ridge which divides the ocean into two basins. This low ridge is called the Dolphin Rise or Ridge, and southwards it tapers off towards the Equator, where it finally disappears. In the north (about lat. 40°N.), the Rise broadens out to form the low submarine plateau on which lie the Azores. Further north still this merges into the Telegraph Plateau.

Another submarine ridge runs from the coast of Greenland to the British Isles and Norway, rising above the surface of the ocean to form the Shetland Islands, the Faroe Islands and Iceland.

In the South Atlantic, along the African coast, the continental shelf is very narrow, although it broadens a little in the extreme south. A few miles from the coast the ocean floor sinks to a depth of over 1,650 fathoms. On the South American coast between the Orinoco River and Cape San Roque the shelf is much broader. It narrows again as far as the La Plata estuary, but from there it widens out considerably to form the Patagonian Shelf which includes the Falkland Islands.

The Indian Ocean

In the Indian Ocean, the continental shelf is everywhere narrow along the African coast, although it broadens a little along the shores of the Mozambique Channel. In the southern part of the Red Sea, also, the shelf is very narrow, but it occupies the whole of the Persian Gulf. Along the east coast of India it is narrower than on the west coast, except in the broad part opposite the delta of the Ganges. In the Gulf of Martaban and in the Straits of Malacca it again appears as a broad ridge. Everywhere round the western coast of Australia the shelf is fairly broad, except for a very short section just off the extreme south-west corner. On the whole, the floor of the Indian Ocean is very level. The greatest depth (about 3,800 fathoms) is registered at the Sunda Trench, south-west of Java.

The Pacific Ocean

The Pacific Ocean is roughly triangular in shape. The American seaboard is very regular, but the Asiatic coast is much broken and is fringed with many islands. A feature of this ocean is the immense number of coral islands that dot its surface, particularly in the southern

part. The average depth is nearly three miles, the greatest depth being off Mindanao Island in the Philippines—about 5,300 fathoms. Along the American coast the continental shelf is narrow and the sea floor falls rapidly to the level of the deep sea plain. On the Asiatic sides the formation is similar except in the semi-enclosed seas, which are shallow.

Temperature of the Oceans

The temperature of the surface water of the oceans varies much more than that of the water under the surface. This is because the surface water is affected by the heat of the sun's rays and the air at its surface, so that it becomes very warm at the Equator and relatively cold at the Poles. Moreover, as water heats and cools more slowly than land, the temperature of the ocean surface is much more uniform than that of the land, and this tendency is assisted by the continuous movements of the water, which carry the cold surface waters towards the warmer latitudes and the warm surface waters towards the colder latitudes in a continuous circulation or exchange.

Owing to the fact that water is a poor conductor of heat, the warming influence of the sun on the oceans is not effective to a greater depth than a few hundred feet. From the surface the temperature rapidly decreases at first, but below a few hundred feet the decrease is very slow and, indeed, the temperature of deep water is nearly uniform throughout the world, temperature tests taken near the floor of the ocean at the Equator and near the Poles showing little variation.

As would be expected, the surface temperature of the oceans is more uniform in mid-ocean than near the coasts. Whereas summer and winter temperatures near the land masses show a fairly wide variation, in mid-ocean the difference is one of a few degrees only. Even at the coasts, however, the range of temperature is not very great, except off Newfoundland and Japan, where, owing to special conditions, the temperature variation exceeds 50°F. In these areas there is at one season a current of water from the Arctic Region, and at another a warm current from the Tropics, which conditions, and not the heating and cooling of the same body of water, account for the marked difference in temperature.

In the Polar regions the waters of the oceans are permanently frozen to a depth of up to about 9 feet. These great expanses of ice are called ice-sheets, parts of which at times break up and become piled up into great irregular masses known as pack-ice, which is particularly dangerous in the Arctic Ocean.

Salinity of the Oceans

The saltness, or salinity, of seawater, is due to the relatively large quantity of salt substances, mostly sodium chloride or common salt, dissolved in it. The oceans are not, however, uniformly saline

throughout, because in certain areas local evaporation under the influence of wind and heat draws water from the sea, and leaves a higher proportion of salt in solution in the remaining water. So we find that in those parts of oceans which experience dry winds, and therefore great evaporation, the surface water is strongly saline. Similar conditions are found in the lower latitudes, where the heat of the sun in combination with the hot, dry winds causes evaporation. On the other hand, in the higher latitudes, and in areas subject to vapour-laden winds, the salinity of the water is relatively low. Thus, the average salinity of the water of the oceans has been estimated at 3½ per cent., which means that in every 100 lbs. of seawater there are 3½ lbs. of dissolved salts, but near the Arctic and Antarctic Circles the salinity is only 3.2 per cent., whereas at the Tropics of Cancer and Capricorn it rises to over 3.8 per cent.

Another factor affecting salinity is the presence of large rivers flowing into the ocean, for fresh water brought down by the rivers dilutes the normal seawater. In the Mediterranean Sea and the Red Sea, where evaporation is very great, and where there is little rainfall and few rivers of any size, the waters are very salt, their salinity being 3·7 per cent. and 4·0 per cent. respectively. This is in sharp contrast to the Baltic Sea, where the salinity is only 1·2 per cent., partly as a result of the heavy inflow of fresh water from the large rivers which flow into the sea, and partly as a result of the frequent heavy falls of rain and snow. In the equatorial regions, too, the almost continuous heavy rainfall lessens the salinity.

Totally enclosed seas, especially those which are not renewed by enough fresh water to maintain their volume, have an extremely high salinity, owing to the accumulated salt in their waters, and occasionally, when such seas partly dry up, great rocks of salt are laid bare.

The presence of dissolved salts necessarily makes the waters of the oceans denser than fresh water, and also accounts for the facts that sea water does not freeze so readily as fresh water (the freezing point of fresh water is 32° F. while that of the average sea water is about 28° F.) and that it is possible to swim more easily in sea water than in fresh water.

Influence of the Sea

Proximity to the sea has a marked influence on the life of the inhabitants of a country and on its commerce. The most valuable fisheries of the world are found in shallow seas in temperate latitudes. It was the sea which invited man to venture forth and discover new lands and, at the same time, provided the cheapest possible means of transport between lands that were already settled and developed and the new countries which were from time to time discovered. Britain's typically "maritime" situation resulted in the creation of a race of seamen who went forth and colonised new lands the world over, gradually

building up an Empire which now occupies one-quarter of the known surface of the globe. It is to the sea also that Britain owes her mercantile marine—the largest in the world—and her leading position among commercial nations.

The sea also acts as a political boundary, and gives a form of protection against the spread of infectious diseases and against invasion, though, with the rapid development of aircraft, the advantage of sea boundaries from a military standpoint is rapidly disappearing. Finally, the sea has an important influence on climate (see p. 144).

RIVERS AND LAKES

Rivers and Streams

Rivers, streams and lakes form the "land water" of the earth's surface. Rivers derive their water mainly from the atmosphere in the form of rain or melting snow and ice, and partly from underground water or springs. In some cases, they are fed from the overflow of lakes.

The place where a river begins, or rises, is called its *source*, and the place where it enters the sea or any other body of water at which it terminates is called its *mouth*. When the mouth of a river is very wide (due to the submergence of its lower valley), and the tides travel far inland, the opening is called an *estuary* ; and when the river flows into the sea through a number of mouths, or channels, the land enclosed between the various streams is termed a *delta* (see p. 56). A *watershed*, *water-parting* or *divide* is an elevated portion of land which separates one *river basin*, *i.e.*, the area drained by a river, from another. A river basin includes all the low-lying land in the neighbourhood of a river and those uplands whence its tributaries derive their water. Most rivers originate as streams, which gradually increase in size as they run their course. Occasionally, several streams or smaller rivers unite to form one large estuary (*e.g.*, the Plate and the Humber); in other cases streams flow into the main river at various points between its source and its mouth, in which case they are called *tributaries*, *feeders* or *affluents*.

The variation in the flow of water in a river occurs mainly because the amount of rainfall received in the region through which the river flows varies with the seasons or because of the melting of the snows in spring or early summer on the mountains in which the river has its source. The flow of water in the River Thames, for example, varies considerably, being greater in autumn and winter when the rainfall is heavier. Prolonged periods of low rainfall make the water level very low and give rise to drought conditions. On the other hand, the waters of the great rivers of the north of India are swollen by the melting of the snows on the high Himalayas in the late spring, when temperatures begin to rise. Again, the Nile floods in north-east Africa are a result of the monsoon rains experienced on the Abyssinian Plateau, where the

Blue Nile has its source. In some countries, *e.g.*, South Africa, the river courses may even dry up completely in the dry season.

Influence of Rivers

Rivers early achieved importance as guides for nomadic tribes while the level ground on either side offered great advantages as sites for settlements, since the river not only provided food and drink but also facilitated intercourse. To-day, navigable rivers provide a cheap and easy highway for traffic, and their valleys are of great value as natural routes for railways and roads. Where the current is swift or where waterfalls occur, rivers form valuable sources of hydro-electric power. Moreover, they still provide supplies of food and drinking water and, except where they run through gorges, are extremely valuable for irrigation purposes in regions where the rainfall is scanty or precarious. In addition, they frequently act as political boundaries, but this is a feature which is decreasing in importance as rivers are no longer considered to be obstacles in the military sense.

Lakes

A large expanse of water collected in a hollow of the land is known as a " lake ". We may classify lakes as follows :—

1. Barrier Lakes, formed by the blocking up of a river and the consequent holding up of its natural drainage.
2. Rock Basins, or lakes lying in rock hollows, formed by the movements of the earth's crust or by denudation.
3. River Lakes, *i.e.*, lakes which are merely an expansion of the channel of a river, *e.g.*, the lakes of the River Shannon in Ireland.

Barrier lakes have many causes. The river may be blocked by a glacial moraine, such as the Swiss Lakes and those of the English Lake District, or by a lava flow or by landslides ; or the sediment brought down by a tributary may be deposited across the main stream or the main stream may deposit across a tributary ; and in a similar manner a river may be prevented from reaching the sea by the deposit of sand and other beach material across its mouth (the lakes at the mouth of the River Murray in Australia are of this type). (See also p. 54, *oxbow lakes.*)

Rock basins are formed by the folding or faulting of the earth's surface (*e.g.*, Lake Tanganyika in the African rift valley) ; by ice-erosion of the rocks (*e.g.*, Loch Lomond, Scotland, and the lakes of N.E. Europe and of Canada) ; by the mechanical or chemical action of water (*e.g.*, Loughs Ree and Derg, in Ireland) ; or they may be the craters of extinct volcanoes as in the case of certain lakes in Central Italy.

However lakes are formed, they are of a relatively transitory nature, because from the time of their formation they either begin to fill up as

a result of the accumulation of vegetable matter on the floor of the lake and as a result of the deposition of alluvium brought down by streams and of débris brought over by avalanches ; or they are robbed of their water through drainage or evaporation. The draining of a lake may result from the denuding action of overflowing rivers or from the denudation of a lake barrier, whose disappearance permits the water to flow away. Earth movements, too, may cause the disappearance of a lake, particularly when they divert the course of a river which previously fed the lake, whilst a change in climate involving a decreased rainfall may cause a lake to become smaller and gradually to disappear.

The many *salt lakes* found throughout the world are caused either by evaporation or by the isolation of part of the sea through earth movements or the deposition of sediment (*e.g.*, lagoons, Fig. 19). As in the case of the sea, continuous evaporation causes the salt dissolved in the water to be deposited, but if the lake is drained by a river, it will usually be a *freshwater* lake, for the river will drain off the salt substances. In arid districts, the lakes partially or wholly dry up in the dry season and the resulting salt bed is known as a " salt-pan " or " salina ". The best example of a salt lake is the Great Salt Lake of Utah (U.S.A.).

The flow of a river when it enters a lake is frequently checked so that the sediment carried by the river is deposited and forms a lake delta. A delta of this kind completely shut off Lake Derwentwater from Basenthwaite Lake, whilst another separated the Swiss Lakes Thun and Brienz.

Influence of Lakes

If they are sufficiently large, as, for example, the Great Lakes of North America, lakes have the same effects, in miniature, as the sea—influencing climate and products, providing food, a cheap means of transport and, in some cases, acting as political frontiers. In addition, a lake through which a river flows acts as a filter for the river water and controls its flow. By thus acting as a receptacle for sediment, lakes prevent the formation of sand-bars in deltas at the mouths of rivers, and, by serving as reservoirs for excessive water, they minimise the likelihood of serious floods. Natural and artificial lakes are used as reservoirs for the supply of drinking water (*e.g.*, Thirlmere, which supplies Manchester), and for storing water for canals or for use in electric power stations. Another important commercial aspect is their attraction for tourists. In Cumberland and Switzerland, amongst other places, they are for this reason most valuable to the permanent population of the districts in which they are situated.

Inland Drainage Area

An inland drainage area is a region in which the rivers flow inland to a low-lying area instead of outwards to the sea. As the land slopes

down to some point inland, it is cut off from the sea by the upward slopes and hence the rivers flow into the low-lying inland area. Frequently, the rivers flow into a lake formed at the lowest point of the region. An example is the Lake Eyre inland drainage area of Australia, which lies entirely under 600 ft. and from which the land slopes upwards, cutting off the low-lying area from the sea.

THE EARTH'S CRUST

The crust or surface of the earth is a mass of rock believed to have a depth of about 50 miles. The crust is by no means stable. On the contrary, it is subject to continual pressure, movement, expansion, contraction and fracture. The science of geology has placed at our disposal much valuable information concerning the composition, arrangement and changes of the materials forming the earth's crust, and the facts brought to light by geologists are of the utmost importance to the study of geography, particularly in its economic aspect.

Composition of the Earth's Crust

The earth's crust is composed of different kinds of rocks, which have been formed by the gradual cooling and hardening of the outside surface of the earth. The word " rock " is here used in its geological sense to mean " any mass of natural substance forming part of the earth's crust ", and thus includes not only masses of hard stone, such as granite, but also the softer matter, such as sand, soil, clay and gravel, that has been formed by the disruption of the harder masses.

Rocks may be divided into a variety of classes, but the following classification will serve our present purpose :—

1. *Igneous* rocks.
2. *Sedimentary* or *Stratified* rocks.
3. *Metamorphic* rocks.

Sedimentary rocks can be subdivided into *Inorganic* and *Organic* rocks. *Coral*, which we have already mentioned, is an organic rock which stands in a class by itself.

IGNEOUS ROCKS are those which have been formed by the cooling of molten matter from the interior of the earth, and may be sub-divided into :—

Rocks of Volcanic Origin, i.e., rocks which have been formed by the cooling of the lava exuded from volcanoes.

Plutonic rocks, which have slowly solidified at great depths and under great pressure. They become part of the outer surface of the earth's crust through being uplifted by pressure and then " denuded " (see p. 48).

Igneous rocks, of which the most important are basalt and granite, are generally found in mountainous districts, especially those having

volcanic characteristics. Their hard and durable structure enables them to resist weathering, whilst softer rocks on and around them may have been worn away or denuded.

SEDIMENTARY ROCKS or STRATIFIED ROCKS are mainly caused by the action of running water, the sea or wind in denuding and breaking up other rocks, the resulting débris being deposited in layers or strata on the floors of lakes, in river beds, on the bottoms of shallow seas, in valleys, or on plains, where it ultimately solidifies into a mass. In many areas, movements of the earth's crust have brought the sedimentary rocks to the surface, and have also moved them from their original horizontal position, so that they are now to be found lying at all angles and in various positions. Sedimentary rocks frequently contain animal and plant remains known as "fossils", which usually afford valuable clues as to the early history of life in the region.

This class of rock is still being formed by the action of the wind, of the sea and especially of rivers which bring down sediment and deposit it in the form of alluvium, the heavier part of which settles first and in time forms sandstone.

Inorganic Rocks.—Most sedimentary rocks are inorganic, *i.e.*, are formed mainly of mineral matter. Examples are sandstone, clay, shale and gravel. The hardest of these rocks are usually the oldest, as they lie deep and have been much compressed.

Organic Rocks, as their name indicates, are sedimentary rocks formed from the hardened remains of plants and animals, which have gradually been buried deep in the earth's crust and their composition altered by gradual decay. Coal, the most important of such organic rocks, has been formed in this way by the submergence of trees and plants, and for this reason we know that the areas in which there are now coalfields were once covered with forest. Limestone, again, is formed of the skeletons of myriads of tiny marine animals. Coral, chemically, is limestone, and though it can be classed as organic since it is built up by the action of *living* organisms, it is not correctly described as sedimentary. Mineral oil is the product of the remains of plants or animals which have been covered by mud deposited on the floor of a lake or of the sea.

METAMORPHIC ROCKS are igneous or sedimentary rocks which have undergone great alterations in structure and composition through the agency of heat, water and pressure at great depths. As a result of the action of these agents, the rocks when cooled have become hard and crystalline. Marble, which is limestone that has been fused under enormous pressure and has subsequently crystallised, is the best example of this type of rock. Other examples are slate and anthracite, *i.e.*, hard or "steam" coal. The process of change in the case of metamorphic rocks extends over a great many centuries, for they have first to be buried by earth movements, then hardened, again brought to the surface by further movements of the earth, and finally cooled.

Geological Periods of Rocks

It has already been stated that the rocks forming the earth's crust are subject to constant changes, with the result that different types of rocks appear in close proximity and the rock structure of the land masses is very complicated. It is possible, however, by studying the remains of life-forms found in the rocks to make a classification according to age. This is eventually a question for the geologist, but the main divisions with their chief features are important in the study of geography, and so are given briefly below.

PRE-CAMBRIAN PERIOD.—The rocks of this class are the oldest known, and very little evidence of life has been discovered in them. They include gneiss and granite, and frequently contain deposits of valuable minerals, such as iron and gold.

PRIMARY PERIOD.—This followed the Pre-Cambrian period and one of its sub-divisions is the important *Coal Age* or *Carboniferous Period.* The chief rocks of the Primary Period are shale, slate, hard sandstone and limestone, all found widely distributed in Wales among the Cambrian Mountains, which fact is responsible for the name—Cambrian—given to the most prominent group of the Primary Period.

The rocks of this period include also large deposits of minerals, *e.g.*, gold, oil, coal and iron in North America ; tin, iron and copper in Europe.

SECONDARY PERIOD.—Included in this class are soft sandstone, chalk, clay and limestone. It was during this period that deciduous trees and the first birds appeared. The rocks are not so rich in mineral wealth as those of the previous periods.

TERTIARY PERIOD.—During this period, which was characterised by large earth movements and extensive volcanic eruptions, vegetation increased and the ape-man appeared. The chief rocks are soft clays, sand and limestones.

QUATERNARY PERIOD.—This is the most recent age, during which the vast ice-sheet of the Ice Age covered large areas of Europe and North America and had an important fertilising influence on the soil of these regions. This period, too, was responsible for the alluvial deposits which appear in various parts of the world.

Changes in the Earth's Crust

Changes in the form of the earth's crust are going on continually, and for the most part very gradually. They are brought about : (i) by *denudation*, and (ii) by *elevation and subsidence* of some portions of the crust in relation to the others. Local changes may take place suddenly as a result of earthquakes—technically called " seismal " action.

Denudation

Denudation is the general process by which rocks are worn down by rain, frost, the atmosphere, wind, the heat of the sun, rivers, ice, the sea and other natural agents. The loosened material is usually carried away and deposited elsewhere, chiefly at lower levels. There are thus at least three distinct stages: (1) the breaking up of the rocks; (2) the transportation of the denuded material, and (3) the deposition of this material elsewhere. In places where steep slopes occur, transportation is assisted by the force of gravity and in such cases large quantities of broken rock accumulate at the foot of mountains and cliffs. These accumulations are called " screes ".

The Atmosphere

The erosive power of the atmosphere is due to the chemical action of its constituent elements, which in time causes even the hardest rocks to crumble away. The speed of action varies according to the humidity of the air; in countries with a damp atmosphere the process is much more rapid than in countries which have a dry atmosphere. In the dry air of Egypt the pyramids have been remarkably preserved for centuries, whereas in the moist air of Britain they would long ago have crumbled away. On the other hand, the granites of Cornwall and Devon have been disintegrated and decomposed by our humid climate to form the china clay which is such a valuable raw material of our porcelain industry.

Sand in the atmosphere transported by the wind is a destructive agent. The Great Sphinx of Egypt is badly scarred by the action of wind-borne sand, which smooths the harder rocks but leaves hollows or indentations where the softer rocks have been unable to withstand the force of the sand-blasts. (See also p. 50.)

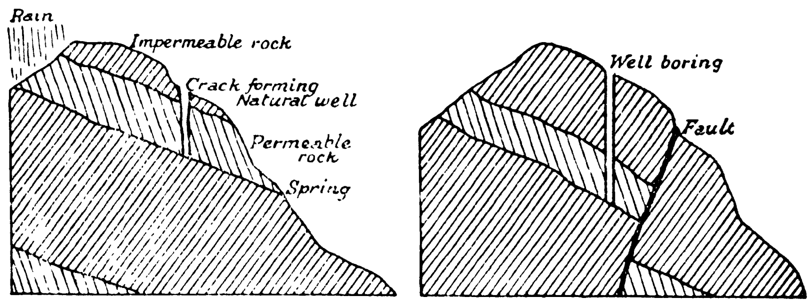
Rain

The action of rain on rocks is both mechanical and chemical. Mechanically, it loosens the soil and carries it away to other parts, whilst by its chemical action it dissolves certain materials which form part of the earth's crust. In hot, relatively dry countries the *mechanical* action of rain is particularly noticeable, for here the rock surfaces are already broken up by variations in temperature and other agencies (see " Heat " below) and are more easily disturbed, but in forested regions and regions of profuse vegetation, the roots of the plants bind the soil together and so prevent rain from damaging the surface.

In passing through the air the rain absorbs a certain amount of carbon dioxide (" carbonic acid gas ") and reaches the earth as a weak

acid solution. This enters into chemical combination with basic rocks (especially those which contain lime in one form or another) and if the resulting compound is soluble, or is soft enough to be removed by the water, it is carried away through the ground or over its surface.

Much of the rain which falls "permeates" through the earth's surface and frequently settles in pools underground. Its chemical action may then continue, and as it flows away, underground caves may be formed by gradual dissolution of the rocks. When the rain-water comes to a layer of impermeable rocks (*i.e.*, rocks which do not allow water to filter through them) it accumulates in hollows and may then make its



NATURAL SPRING AND WELL. FIG. 17. BORED "FAULT" WELL.

way over the impermeable rock until it breaks out at the surface again in the form of a *spring*. This action is illustrated in Fig. 17, wherein the water is shown to flow down a gradient of the permeable rock to emerge as a spring from the hillside.

WELLS are used to tap underground water. They may be either artificial or natural. An artificial well is a shaft or well boring which is sunk down to the natural reservoir; a natural well is a hole or crack caused by earth movements (Fig. 17). Where water rises to the surface through a well, the pressure that forces it up is due to the existence of a head of water accumulated on a sloping surface of impermeable rock, *i.e.*, part of the underground water is stored at a point higher than the place where the water outflows to the surface.

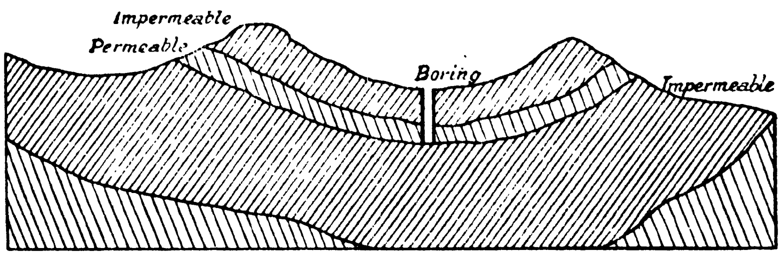


FIG. 18: ARTESIAN WELL.

Artesian Wells, which assume great importance in some countries, such as Australia, are formed where a layer of permeable rock is situated between upper and lower layers of impermeable rock in a hollow of the land. Rain which reaches any permeable rock at the surface penetrates into it and collects underground in the cup formed by the impermeable strata. The pressure due to the height of the water in the permeable rock above the top of the boring forces the water up the shaft (Fig. 18). Where this difference in height is at all marked the water rushes out violently.

Heat

Variation in temperature causes alternate expansion and contraction of rocks as it does in the case of other materials, and these movements, as they take place very unequally in the rocks, produce violent stresses which cause cracks. As contraction and expansion are repeated, these cracks extend until pieces of rock become detached. This effect is marked in hot countries, where high exposed places experience very great and very rapid changes of temperature at dawn and sunset.

Frost

The expansive force of freezing water is a very powerful agent in the disintegration of rocks, particularly in cold countries, because when rain falls, water settles in the cracks in the rocks, and at night the expansion of the water as it freezes forces off portions of rock. The altitude and consequent coldness of high mountains makes these regions very susceptible to this kind of denudation. Frost is particularly important in the disintegration of soils, for the freezing of water and its consequent expansion after it has sunk into solidified soil breaks up the soil into fine particles.

Wind

By carrying dust and sand from place to place, winds are important agents not only in the distribution of materials but also in erosion, especially when strong, sand-laden winds force a continuous stream of sand against the rocks and so wear away the surface. As this action is especially marked near the ground, the lower parts are the more rapidly eroded, while the upper part is left practically untouched and so forms an overhanging cliff, which eventually breaks away.

In some places the winds sweep the ground clean of soil, in others they pile it up into small hills, or *sand dunes*, which in the great deserts frequently reach a height of over 500 feet, whilst on the low coast of

Holland they form a protection against the advancing sea. The rich "loess" soil of a large part of China, and the fertile soil of south-west Russia, have been carried bodily as very fine dust to their present positions by the action of wind.

Ice

This agent of denudation is a very powerful influence in modifying land forms. In high latitudes at all levels, and at increasing heights as the Equator is approached, snow lies all the year round. The snow accumulates continuously, and when the lower layers are compressed by those above them, they form a compact mass of ice, which, owing to the pressure above it and its own weight, moves slowly down the mountain-side like a vast, ponderous stream, called a *glacier*. Like a river, a glacier wears away the surface of its bed to form a valley, and, as it moves slowly forward, it carries beneath it the loose rock fragments it has detached and bears away any that have fallen from the adjacent heights through weathering. These loose fragments are deposited in various places in great heaps and drifts known as *moraines*. Moraines take four forms :—

1. LATERAL MORAINES—the rocks and stones which are deposited along the sides of glaciers, having been weathered from the surrounding surface.
2. GROUND MORAINES—the rocks embedded in the bottom of the ice and gradually ground into small fragments as they are carried along by the movements of the glacier.
3. MEDIAL MORAINES—formed by the joining of two lateral moraines where two glaciers unite.
4. TERMINAL MORAINES—the débris deposited when the ice melts away where the glacier terminates.

By the combined movement of a glacier and of the rocks it carries with it, the rocks over which it passes are scratched and worn. The smoothness of rock surfaces and the scratches on such surfaces in various regions are evidence that at an earlier period, called the *Ice Age*, a large part of the earth's surface was covered by moving ice.

In the Polar regions, where the glaciers extend for some distance into the sea, large blocks of ice from time to time break off from the major masses and float away into the lower latitudes. These are the *icebergs* which are so dangerous to shipping. When an iceberg reaches warmer latitudes it melts, and the débris embedded in it is deposited on the ocean floor. In those places where the icebergs melt very quickly, as, for example, where a cold ocean current meets a warm current, the

quantity of débris thus deposited is enormous, and in the course of time it may build up extensive *banks*. Thus, off the coast of Newfoundland, where the cold Labrador Current meets the warm Gulf Stream (see p. 109), the mass of débris deposited year after year has formed the famous Newfoundland Banks.

The Sea

The sea acts as an agent of denudation, of transportation and of deposition. It denudes both by *erosion* and by *corrosion*.

The extent of the erosive action of the sea depends chiefly on the composition of the rocks forming the coast-line. Moreover, the loss of land due to sea-erosion at some parts of the coast is balanced at other parts by the gain due to the gradual elevation of land above the level of the sea, and also by the deposition of sand and shingle.

The erosive effects are obvious from a study of the coastlines of the land masses. The continual beating of the sea against the land washes away the softer rocks, so that some parts of the coastline are indented, forming *bays*, *gulfs* and *inlets*, whilst other parts jut out into the sea, forming *capes* and *headlands*. In some cases we find the coast eroded to form long stretches of steep *cliffs*, as, for example, those of Dover and the neighbouring coastline, while elsewhere the hard rocks remain as *islands*, sometimes rising steeply from the water, as in the case of the pinnacle-like " Needles " off the Isle of Wight. The sea usually carries with it a quantity of loose material which is thrown forcibly against the land in stormy weather and assists in the erosive action. This loose matter—the débris rocks which have been broken off and have afterwards been ground and pounded into smaller particles—forms sand and shingle (pebbles).

The corrosive action of sea-water is largely due to the carbonic acid which it contains. This has a particularly marked effect on limestone cliffs, which it eats away from beneath and brings down in a succession of landslides. Much the same effect is brought about by the erosive action of the sand borne by the water. This suspended material reinforces the action of the currents and waves on the rocks with which they come in contact, and wears the rocks away to form channels and caves.

The rock waste or beach material in the form of sand and shingle is carried backwards and forwards by the movements of the oceans, and, as the forward movement is stronger than the backward movement, the larger stones pile up on the higher parts of the shoreline. Where the direction of the prevailing winds or of coastal currents tends to be parallel to the coastline or not directly on-shore, the waters are driven in the same direction, and in this way material is transported from one part of the coast to another, where it is deposited in the form of *bars* or *forelands*. Other deposits may occur between an island and the mainland, thus forming a *peninsula*, or across the mouth of an inlet,

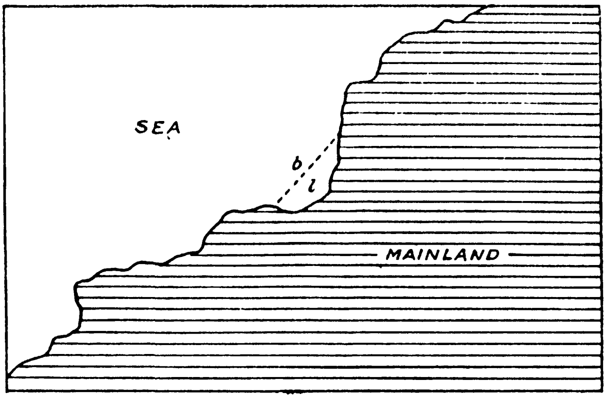


FIG. 19: LAGOON. (b = bar; l = lagoon).

forming a *lagoon* (Fig. 19). Part of the eroded material is carried out into deeper water, where it is deposited on the sea floor.

Rivers

Rivers change the surface of the earth in four ways: (i) by eroding or cutting away their beds and banks; (ii) by dissolving or corroding the rocks over which they pass; (iii) by transporting material from their upper course, and (iv) by depositing eroded or transported material in their lower parts.

River water is even more highly charged with various active compounds than is rain water, which, as we have observed, can dissolve limestone rock. In addition to carbon dioxide, the water of rivers often carries soil-acids derived from decaying vegetation (*e.g.*, "humic" acid, from humus). These compounds have a strong effect on limestone and other rocks, and in combination with them form valuable soils. On the other hand, water containing them has been known to attack and dissolve the metal of lead pipes and so cause an epidemic of lead poisoning.

The denuding action of rivers can best be understood by considering the course of a typical river as consisting of three divisions: the "*alpine*" or "*torrent*" tract (*i.e.*, the upper course), the "*valley*" tract (*i.e.*, the middle course) and the "*plain*" tract (*i.e.*, the lower course).

ALPINE TRACT.—The water which drains the high land to form the beginning of the river begins at once to form or excavate for itself small hollows in the surface of the earth. The matter or sediment excavated is carried along by the force of the stream and erodes the channel, until in time steep-sided gullies and ravines are formed. This erosive action is accentuated by the action of eroded rocks which fall into the stream and are carried along by the water, especially when the stream

is swollen by heavy rains. When the course of the river is not straight, the erosive action is twofold, for the water as it sweeps round a bend is forced more against one side than the other. In such cases the stream wears away the lower part of the bank as well as its bottom, and the portions thus undercut fall into the stream.

Valley Tract.—The middle course begins where the river has left the high land of its source and has reached fairly level country. There may still be falls and rapids, and certain rivers, especially those which fall from a high plateau or tableland, are continually descending steep slopes, and have no middle course in the true sense of the term.

Normally, however, the flow of a river is retarded in its middle course, both by the more gradual slope of the ground and by the mass of material it is transporting. As a result, the process of excavation almost ceases so far as the bed is concerned, while the larger eroded rock fragments are left behind, only the smaller ones being carried along. The river, however, continues to corrode its banks and to widen its valley.

In time the irregularities of the banks are washed away and the river flows over the plain in wide curves. When the curves or meanders become very pronounced their extremities gradually approach, and finally they may join up and form a straight course for a time (Fig. 20). But the river continues to corrode its new banks, and ultimately again resumes a meandering course. The part of the river cut off where two curves join, known as an *oxbow lake*, will in due course dry up.

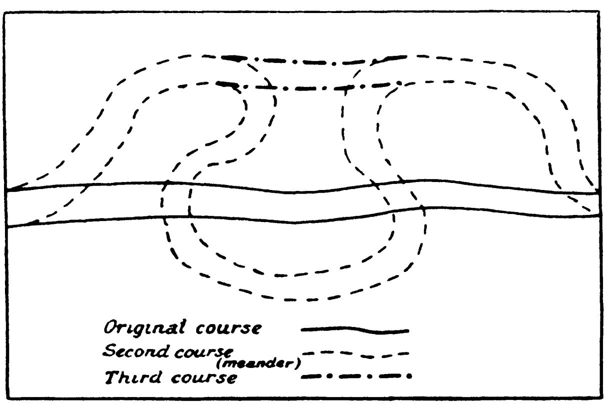


Fig. 20: River "Cycle."

The plain formed by the denuding action of a river, whereby all inequalities of relief are worn away, is called a *peneplain*. After heavy rains rivers frequently overflow their banks, in which case the area subject to the floods is termed a *flood-plain*, and is usually covered by fertile deposits of *alluvium* carried by the rivers and left behind when the flood waters retire. Rivers which are subject to floods usually carry an enormous amount of silt, which they deposit on each side of their

course, and gradually raise the level of the river bed and its banks as well as the flood-plain above that of the surrounding country. When this stage has been reached, a river flood may prove particularly disastrous, for the water may break down its naturally raised banks and find a new course through populated districts. Such floods have at times destroyed whole villages, causing great loss of life and property, and in many places it has been necessary to build up artificial banks to ensure safety. In other parts, however, the rich loam or alluvium spread by floods over the surrounding country is of the greatest economic importance in making the land extremely fertile. The annual floods of the River Nile, for example, not only fertilise the surrounding land, but also provide abundant supplies of water for irrigation purposes.

Plain Tract.—The rate of flow of a river when it nears its mouth is much diminished. It is often heavily loaded with solid matter and when the river meets the sea, two forces operate to cause this matter to be deposited; first, the reduced speed of the water, and, secondly, the peculiar chemical effect of the salts in the sea-water. They cause the suspended colloid matter, of which at this stage most of the solid content consists, to coagulate and fall rapidly to the bottom of the water. This produces a pronounced deposit about the mouth of the river, and the banks of silt so formed often cause the river to divide into several channels separated by fan-shaped islands. This process of deposit of sediment and subdivision of the river is the typical development of a delta (Fig. 21).

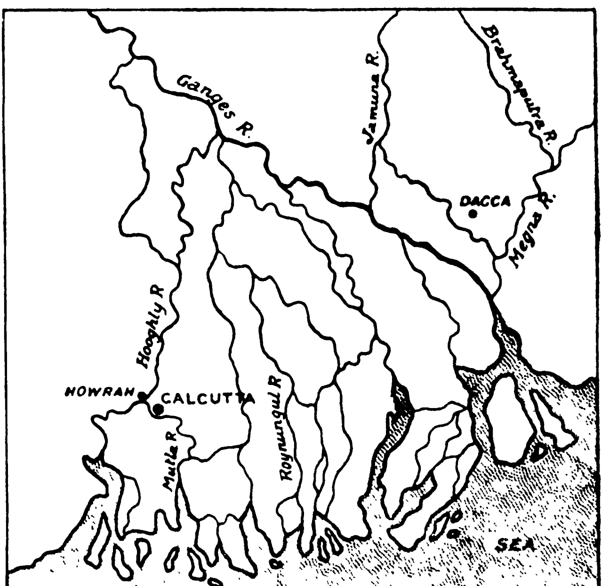


Fig. 21: Mouth of the Ganges and Brahmaputra Rivers.

The thick line indicates the course of the main stream of the Ganges.

A *Delta* thus consists of an area of alluvium brought down by a slow-flowing river and deposited at its mouth, the alluvium being intersected by the many channels through which the river reaches the sea. A very swiftly flowing river will not, of course, form a delta, for it will have sufficient momentum to carry its sediment some distance out to sea. Nor will deltas be formed when the movements of the ocean are such as to keep the estuary or mouth of the river free from silt and sediment. Owing to the fertility of their soil and to the ease which the land can be irrigated, deltas are usually very productive and densely populated, *e.g.*, the delta of the Ganges. An outstanding example of land building by rivers occurs in Italy, where the River Po is steadily depositing sediment and causing the land to encroach gradually on the Adriatic Sea.

Where a fast-flowing tributary joins a river which is moving more slowly, the larger and heavier rock fragments carried by the tributary will be deposited, thus creating what is termed an *alluvial fan* or *cone.*

Falls and Defiles

Such river formations as falls, rapids, gorges, ravines and cañons occur owing to the differing degrees of hardness of the rocks forming the river bed. Where hard and soft rocks lie close together, the softer rocks are rapidly denuded, whilst the harder rocks offer greater resistance. As a result, the hard rocks are left standing above the softer rocks, and the water flows over them in a steep decline (*falls* and *rapids*), or through them in a narrow defile (*gorges*, *ravines* and *cañons*).

Some steep-sided valleys, such as the cañons of western United States, are formed partly as a result of the hardness of the rocks, and partly as a result of the dryness of the climate, for in such conditions very little weathering of the rocks takes place.

When a river meets a belt of hard rocks in its early life, it is unable immediately to cut a definite channel and is forced to broaden out and to flow over the hard rocks in more or less parallel streams. Gradually, however, it cuts out a main channel flowing through a gorge and its bed then narrows above the gorge. When the narrowing process begins, the river may actually divide above the gorge, and the branches thus formed may rejoin the main river below the gorge. As the main stream deepens, however, the parallel streams break and become tributaries flowing through the soft rocks of the flood plain to join the mainstream below the gorge. Some of them, especially those above the hard belt, may dry up, but the remainder often indicate the courses of what were formerly divisions of the main river. Fig. 22 illustrates a possible formation after definite gorges have been formed: the two tributaries

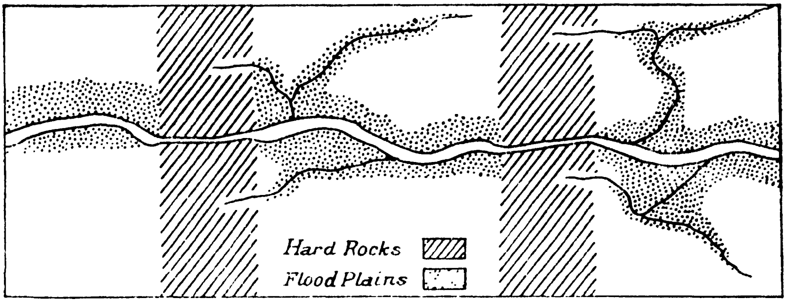
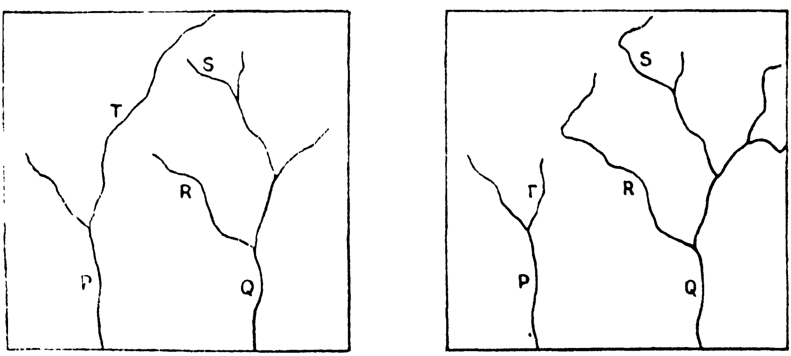


FIG. 22: RIVER FORMATION THROUGH HARD AND SOFT ROCKS.

at the top of the Figure and on opposite sides of the right-hand ridge of hard rock are the remains of what was once a single stream flowing across the ridge from a higher part of the main stream to a lower part.

River Capture

Where two rivers flow in close proximity to one another, the tributaries of one may "capture" the waters of the other. This is caused by the nature of the rocks. Thus, in Fig. 23, rivers P and Q are flowing close together in the same direction, but owing to the softer rocks in its course, river Q develops much more quickly than river P. Consequently,

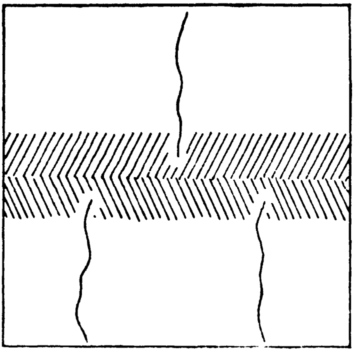


COURSE OF RIVERS BEFORE CAPTURE. COURSE OF RIVERS AFTER CAPTURE.

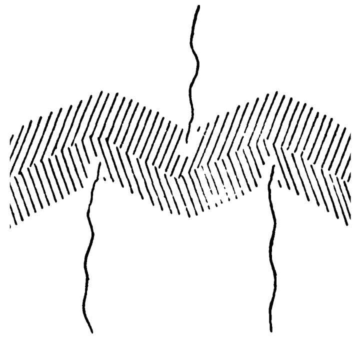
FIG. 23.

the tributaries of Q "capture" the waters of P, thus gaining in importance at the expense of P. In the Figure the tributary R has encroached on the waters of T and "captured" its course, whilst the tributary S has "captured" the upper part of T. This encroachment

usually arises through the "cutting back" of river valleys, which transforms a straight watershed into an uneven one (Fig. 24). There are



ORIGINAL STRAIGHT WATERSHED.



ZIG-ZAG WATERSHED DUE TO "CUTTING BACK."

FIG. 24.

numerous examples of river capture, *e.g.*, the Yorkshire Ouse has captured the head stream of the Swale and other rivers which formerly ran to the North Sea.

The capturing of the water of a river by another may cause the valley through which the water formerly ran to become dry. A "dry valley" may also be formed when underground water removes material below the surface of the land, thus causing a gradual subsidence until the valley is formed.

Elevation and Subsidence of the Earth's Crust

The elevation and subsidence of the earth's crust are a result of movements in the interior of the earth and of weaknesses in the crust, which cause parts of the crust to "wrinkle" or to "fold", or to subside below or rise bodily above the general level of the crust. These movements result in the formation of mountains and valleys.

Earth movements are of two kinds. There is first the continuous, but very slow rising or falling of large areas, such as is now occurring in North and South America, where the west coast is gradually rising and parts of the east coast are gradually falling. This phenomenon occurs also in other places, such as Scandinavia, Eastern India and many of the East Indian Islands, in all of which the coasts are rising; likewise on the east coast of Australia and on both sides of the English Channel, where the coasts are falling. Secondly, there is the cataclysmic shock of earthquake movements, which do not, however, cause such vast changes as the less perceptible but long persistent changes of form. By these movements the surface of the earth has been considerably disturbed, and rocks which were originally laid down in more or less even and horizontal layers have been tilted in all directions and broken up.

In some areas, the movements have caused the surface of the earth to become "folded" into mountains and valleys and have transformed plains into mountainous country, but such changes have been very gradual and have probably gone on for thousands of years. Such a change is illustrated in Fig. 25, where the continuous line shows the surface as it was originally, and the several dotted lines show the

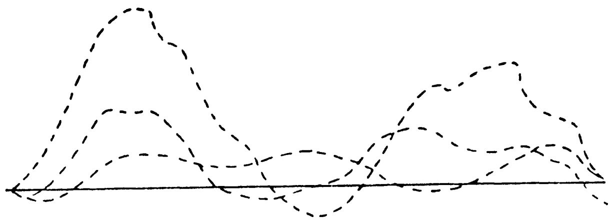


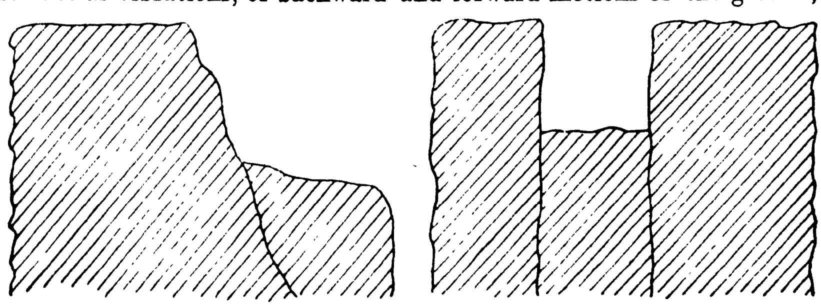
FIG. 25: ROCK FOLDING.

gradual folding process resulting in the present day formation. Movements of this kind not only produce mountains and valleys, but in some cases also cause land to sink below sea-level or may even lift the sea bottom above the surface of the water.

Sometimes the rock cracks and part of it slips down or is lifted up so that the stratum is discontinuous and what is known as a *fault* occurs (Figs. 17 and 26). Where two parallel faults occur the rocks between them slip down and form what is known as a *rift valley* (Fig. 26), as, for example, the rift valley forming the Central Lowlands of Scotland. In other cases part of the crust rises vertically above the surrounding surface between two parallel faults and forms what is known as a *block mountain*, such as the Vosges Mountains of Europe. Rock movements of this kind may also be accompanied by earthquakes.

Earthquakes

The folding, faulting or slipping of rocks frequently causes earth tremors, which we call "earthquakes". These are felt at the earth's surface as vibrations, or backward and forward motions of the ground,



SIMPLE FAULT. FIG. 26. DOUBLE FAULT FORMING A RIFT VALLEY.

which travel outwards as waves from the centre of disturbance. The waves radiate from the " focus ", *i.e.*, the actual place of origin of the earthquake beneath the surface, in all directions as concentric circles. The point on the earth's surface that is the centre of these vibrations or concentric circles is called the " epicentrum " or " epicentre ", which is directly above the focus.

Shocks caused by mass movements of the interior are experienced over very wide areas, and in many cases result in great damage to life and property. Such movements generally occur where the earth's crust is weakened by denudation or contraction and where the pressure on the rocks in the interior of the earth is therefore lessened. This allows the heated rocks to expand (they may even become molten) and the yielding crust eventually cracks and folds. The most violent earthquakes occur in the regions of the folded mountains lying near the sea, usually because the continual action of the sea on the land causes a great weakness in the structure, or in high mountain regions subject to heavy seasonal rainfall, as in India, where the agency of the weather is continually reducing the weight of the mighty Himalaya Mountains.

The effect of an earthquake is very strongly marked when the origin of the shock is beneath the bed of the sea, for in these cases the disturbance may result in the formation of huge sea-waves, which frequently do enormous damage. Earthquakes which are accompanied by volcanic eruptions are not usually so violent as those which are unaccompanied by eruption.

The main line of weakness can be traced from Fig. 28. Commencing from the south of South America, it runs north up the west coast of the Americas, following the main trend of the high Andes and Rocky Mountain systems. From Alaska it crosses to the Kamchatka Peninsula in eastern Siberia (Russia) and then south to the mountainous, unstable islands of Japan, the Philippines, New Guinea, the eastern South Pacific Islands and New Zealand to Antarctica. From the neighbourhood of New Guinea, a branch runs through the high mountainous islands of the East Indies to the highlands of Burma, the Himalayas of India and the mountains (*e.g.*, the Alps) of southern Europe.

Volcanoes

The typical volcano is a conical hill surmounted by a relatively small hollow, called a *crater*, which communicates with the interior of the earth by a pipe or funnel through which issue hot vapours, gases, rock fragments and streams of molten rock known as *lava*. The lava flows over the crater sides and down the hill until it becomes cool and solidifies. Frequently, escaping gases make the surface of the lava streams full of holes and as it also cools and solidifies more rapidly than the underlying lava it is broken up into fragments known as *scoriae* or *pumice stone*. The larger rock fragments ejected from the pipe and crater by

a volcanic explosion are called *breccia*; the smaller fragments become *volcanic ash* or *cinders*, whilst the very fine particles are known as *volcanic dust*. When liquid lava is thrown into the air by an explosion it may cool and solidify before falling to earth, forming round or pear-shaped masses known as *volcanic bombs*.

The cause of a volcanic eruption is not yet clearly known. The pressure exerted by the great weight of rocks above would appear to make it almost impossible for the interior of the earth to be anything but solid rock. The occurrence of volcanic eruptions, however, which throw out great streams of lava, suggests that there may be reservoirs of molten rock beneath the surface or that the hot rocks become molten when pressure from the rocks above is lessened, *e.g.*, by denudation or earth movements. Again, pressure induced by earth movements may force molten rock to the surface or water may percolate through a fault or crack in the earth's surface and on reaching the heated interior be transformed into steam, which owing to its expansive force causes an explosion that forces the lava to the surface. In whatever way the phenomenon is caused, however, the lava and other matter is ejected through a part or parts of the earth's crust that has been weakened by denudation, by earth movements (*e.g.*, folding or faulting) or by contraction.

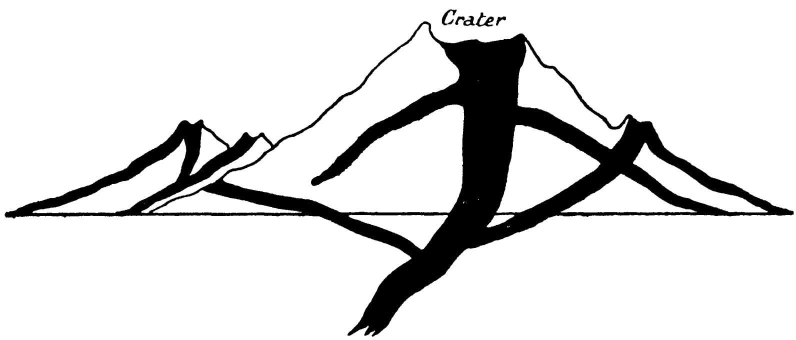


FIG. 27 : VOLCANOES (dark shading = lava).

A volcano which is in eruption or is liable at any moment to break out is called an *active volcano*, but one which has shown no signs of activity for a long time is said to be *extinct*. A volcano which is quiet but may break out again is called *dormant*, and in such case the neck or pipe is generally filled with débris. In many cases, the craters of extinct volcanoes become lakes.

Where the crust of the earth is weak in several adjacent places, groups of volcanoes are found which are active or dormant simultaneously, or there may be one great volcano with several vents (Fig. 27). When a new volcano breaks out, volcanic matter is often emitted from a long rift in the crust of the earth and the characteristic conical form is not

acquired until some time has passed and heaps of débris have formed along the rift. The cones are naturally subject to weathering agents and may in time disappear, the harder rocks being those which remain the longest. A volcano may even alter the relief of surrounding country by making it a plain of volcanic material.

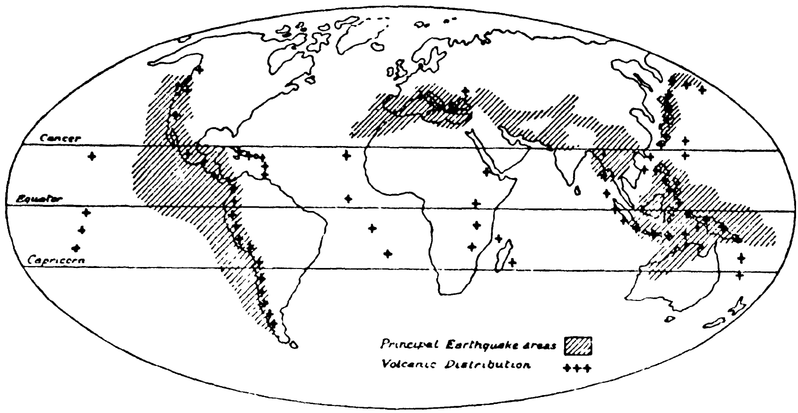


FIG. 28: APPROXIMATE EARTHQUAKE AND VOLCANIC AREAS OF THE WORLD.

Fig. 28 reveals that volcanic activity is most prevalent along lines of weakness in the earth's crust, usually near the sea. Thus, the whole of the west coast of the Americas is a volcanic area, whilst a great chain of volcanoes runs from the Aleutian Islands in the Bering Sea, through the Kurile Islands, Japan, the Philippine Islands and the East Indies to New Zealand. The islands of the eastern Atlantic Ocean, from Iceland to St. Helena, are of volcanic origin, and many of the coral islands of the Pacific and Indian Oceans stand on volcanic formations. The active volcanoes in Europe are restricted to the south of the Continent and the eastern Mediterranean.

Geysers and Hot Springs

Geysers and hot springs occur in volcanic areas where the volcanoes have ceased to be active. They really represent the "dying kick", as it were, of old volcanoes, and exist chiefly in the volcanic districts of Iceland, New Zealand and the Yellowstone Park of the United States. A *geyser* is a natural shaft, or "pipe", through which steam or hot water gushes at more or less regular intervals. *Hot Springs* are similar to geysers, but lack their explosive force.

Solfatara

When an almost extinct volcano continues to send forth vapours such as steam and gases, including sulphurous vapours, it has reached what is known as the *solfatara* stage, so-called after the volcano

Solfatara near Sicily in Italy. In some cases the sulphur is released from the vapours and deposited around the volcanic cone, thus providing valuable sources of sulphur, as in Italy.

LAND FORMS

The forces continually shaping the earth's crust have caused its surface to assume a very uneven appearance. This unevenness we refer to as *Relief*, of which mountains, plains and valleys are the main divisions. The nature of the relief may be mainly—

1. STRUCTURAL in form, *i.e.*, formed by earth movements ; or
2. SCULPTURED or ACCUMULATED, *i.e.*, formed by the agents of denudation.

Mountains

We usually call high land which rises to a considerable height a *mountain*.

Mountains formed by folding movements are called *folded* mountains. They usually run in parallel ranges, such as those of the Alps. Mountains may also be formed by the action of the denuding agents, in which case they are called *mountains of denudation*. The chief of the denuding agents are rivers, which in many parts of the world have carved out valleys, leaving the higher parts standing up as mountains. But we frequently find, too, that denudation arising from the action of rain, rivers, wind and glaciers has worn away the softer rocks of a plateau or tableland, leaving the harder rocks standing out as hills or ridges. Such sculptured plateaus are known as *dissected plateaus*, *e.g.*, the Highlands of Scotland, and the high parts as *residual mountains* (*e.g.*, the Sierras of Central Spain). A third type of mountain is the *mountain* or *hill of accumulation*, and in this class we place sand dunes and volcanoes. Finally, there is the type known as the *block mountain*, mentioned on page 59.

The general appearance of mountains varies considerably. Some have rounded summits, others are much broken and present a jagged appearance ; whilst the slope may be gentle and regular, or precipitous and irregular. These differences are due largely to the type of rock of which the mountains are composed and to the nature of the weathering agents. Hard rocks resist weathering but the softer rocks are quickly worn away leaving the harder rocks standing out in bold relief. It will usually be found that, given similar conditions, each type of rock formation exhibits a uniform outline in appearance wherever it outcrops over a wide area.

Mountains composed of horizontal rocks present a terraced formation, the harder rocks forming steep sides or scarps and the softer more gentle slopes. A combination of steeply-dipping igneous and sedimentary rocks

gives mountains a jagged and irregular outline, and is characterised by steep, inhospitable cliffs like those of Great End, near Scafell. The rounded, slender hills or "tors" of south-western England are formed of granite, which weathers very slowly to form smooth, undulating heights. Mountains formed of slate, such as Helvellyn, also have even, gentle slopes, although steep ridges will occur where the rocks dip sharply. Running water wears the rocks smooth with gentle slopes, whereas rapid changes in temperature or severe frosts cause fragments of rock to break away thus leaving jagged, sharp and steep outlines. In arid countries, irregular rock formations occur as a result of the action of sand-laden winds or through the action of occasional torrential rains on jointed, stratified rocks.

Prominences which rise only a relatively short distance above sea-level or above the general level of the surrounding country are known generally as *hills*, although they receive different names in different countries. Thus, the low chalky or sandy hills of England are called *downs*; the sand hills on the coast of Flanders are called *dunes*; and in Devon the low, abrupt, usually rounded hills are called *tors*. Ridges with a steep face or scarp on one side and a more gentle slope on the other side are called *escarpments*, *e.g.*, the limestone escarpment of south-east England.

The great mountain systems of the world run in more or less parallel *ranges*, *ridges*, or *chains*, which are separated by stretches of low-lying country called *valleys*, or by elevated but level expanses known as *plateaus*. Smaller mountains are often grouped in clusters which have no common direction, and which may even be circular in form.

Valleys are said to be *longitudinal* when they run parallel with a mountain range, and *lateral* when they cut through or into a range. Lateral valleys have invariably been formed by the action of rivers in their descent down the mountain side into the longitudinal valleys, which frequently mark the course of important rivers drawing most of their water from the smaller streams of the lateral valleys. Like other types of lowlands, valleys greatly facilitate the construction of railways, especially as they open up otherwise impenetrable mountainous regions.

Mountains are frequently a great hindrance to communication, forcing people to make long detours or to build tunnels. Rivers, however, often wear their way through mountains and form *gaps*, which are utilised for railways and roads; in other cases, communication is made easier when advantage is taken of a *pass*, *neck* or *col* formed by a depression in the mountain range. As mountains are easily guarded, they form convenient political barriers, and economically they are important when they are the source of rivers which can be used for navigation, power and irrigation.

The most important effect of mountain groups is their influence on the precipitation of moisture. They intercept winds and force them

upwards, with the result that the water-vapour condenses and falls. This means that on one side of the group there is a well-watered district which supports heavy vegetation, whilst, on the drier side. which the wet wind does not reach, the rainfall is much lighter and the vegetation is usually grassy. These two broad characteristics are modified by variations in altitude and we get a great range of vegetable and animal products and, consequently, of occupations, in a comparatively small area.

This variety of products is, of course, increased by the presence of mineral deposits. These, especially those of metallic ores, were originally formed deep down in the earth's crust, and they are therefore chiefly found in regions where the deep-seated rocks have been uplifted to a great height and exposed, especially on the wet sides of mountains, where the action of the weather in wearing away the rocks is most effective.

Plains

Those parts of the surface of the land which are level, or nearly level, are included in the general term *plains*, although they receive different names in various parts of the world, usually descriptive of the vegetation they bear rather than of their evenness of surface. Thus we have *llanos* in Venezuela ; *campos* in Brazil ; *veldt* in South Africa ; *downs* in Australia ; *steppes* in south-eastern Russia ; *prairies* in North America ; *savannahs* in northern Africa ; *pampas* in the Argentine ; and *parklands* in East Africa. Plains situated at a considerable height above sea level are called *tablelands* or *plateaus* ; a plain which suffers from lack of rainfall is known as a *desert*, whilst plains which are waterlogged are termed *bogs*, *swamps* or *marshes*. In the arctic region the cold deserts, which are a frozen waste in winter and a swamp in summer, are known as *tundras*.

Plains contrast sharply with mountainous regions in the uniformity of their products. Where the climate is suitable they are devoted mainly to agricultural and pastoral industries, the comparatively level land being particularly favourable to large-scale agricultural operations. The same feature also facilitates railway construction, and, generally speaking, is the most convenient type of land formation for human settlement on a large scale.

The plains which usually fringe the coasts of continents are known as *coastal plains*. They are of varying width, for in some places the mountains slope steeply down to the sea, whilst in others the slope is very gradual. Plains of this type, especially where they are very wide, as round the shores of the North Sea and the Gulf of Mexico, are usually fertile and support heavy populations. Their nearness to the sea tempers their climate and leads to their early development. Railways, too, can be easily constructed in these regions and very frequently trans-continental lines follow the coastal plain for long stretches, the only impediment being the rivers which may have to be crossed.

The Coastline

The *coastline* or *shore* marks the boundary between sea and land. Owing to the varying degrees of hardness of rocks, the erosive action of the sea makes the coastline very uneven, some parts jutting out into the sea, and others being cut away. Where a portion of land juts out into the sea, it is termed a *cape*, *point*, *head* or *headland*, *ness*, *foreland*, *promontory* or *naze*, the terms being used almost indiscriminately, although " point ", " naze " and " ness " are the names usually applied to those projections of the coast which have been formed by the deposit of silt by ocean currents. Where the water almost surrounds a piece of land so that it is connected to the mainland by only a narrow neck (*isthmus*), the land so situated is called a *peninsula*. Italy, Iberia, Scandinavia, Africa and South America are all examples of this formation, though Africa and South America are large enough to be classed as separate continents.

The heavily indented coastlines of such countries as Scotland and Norway are due, not to denudation by the sea, but to the subsidence of parts of the coast, which permits the sea to encroach on the land and to flood the valleys and plains, thus giving rise to formations such as *rias* and the well-known *fjords*. Likewise, the elevation or up-lifting of land above sea-level tends to even out inequalities in the coastline, for the old uneven coastline is superseded by the even edge of the uplifted area. The fertile Carse of Gowrie, on the east of Scotland, consists of marine alluvium which has been uplifted in this way.

QUESTIONS ON CHAPTER 3

1. State what you know about glaciers and earthquakes. (*S.A.A. Prelim.*, *Nov.*, 1931)
2. Write down what you know about earthquakes, comets, icebergs. (*S.A.A.*, *Prelim.*, *Nov.*, 1929)
3. (*a*) Give a simple explanation of the cause of earthquakes.
   (*b*) What is the meaning of the terms " Focus " and " Epicentre " as applied to earthquakes ?
   (*c*) Where are earthquakes most frequent ? (*C.I.I. Associateship, Fire Branch*, 1931)
4. Indicate the principal regions of the world's surface affected (*a*) by volcanic activity, (*b*) by earthquakes. To what are these phenomena attributable ? (*I.C.W.A. Prelim.*, *June*, 1931)
5. Discuss, briefly, any *three* methods by which lakes have been formed. Special credit will be given for relevant sketches. (*C.S.*, *Dec.*, 1926).
6. Illustrate by means of reference to definite examples the uses and modes of formation of lakes. (*L.M.*, *June*, 1925)

7. Some mountain ranges have rounded summits and gently sloping sides, others rise to jagged peaks and have craggy, precipitous slopes. Explain, by reference to definite examples, the various causes that may bring about these contrasts. (*L.M.*, 1925)
8. What evidence is there, other than actual earthquakes, that movements of the earth's crust have taken place from time to time? Support your statement by reference to actual examples. (*D.S.C.*, 1929)
9. What is a river delta? Under what conditions are deltas formed? (*D.S.C.*, 1929)
10. What are the typical parts of a river's course and in what respects do they differ from one another? (*C.S.C.*, 1928)
11. Give an account of the configuration of the sea-floor to the west of Europe. (*L.M.*)
12. State what you know of the formation of glaciers. Why are there none in England? What is a moraine? (*I.C.W.A. Prelim.*, 1933)
13. Describe the more important types of mountain regions. (*C.S., April*, 1934)
14. What is the cause of waterfalls? Do they seriously check the development of a country? (*C.I.S. Prelim.*, 1934)
15. Choose any *five* of the following terms. Explain what is meant by each of the five and give an example to illustrate your answer: Escarpment, flood plain, basin of inland drainage, continental shelf, moraine, dissected plateau, rift valley. (*C.S., Feb.*, 1938)

CHAPTER 4

MAP MAKING AND MAP READING

It is most important in our study of Geography that we should be able to visualise, as it were, the " lie of the land " in the various parts of the world. To assist us in this regard, some permanent record of political divisions, of physical features and of relief is essential, and such records, which have been made of nearly every part of the earth's surface, are called *maps.*

Importance of Map Study

The study of maps is a very important part of the study of Geography, for a map is intended to give an accurate and informative representation of the area to which it relates. Moreover, it is easier to view the related parts of Geography in their correct perspective from a map than from the reading of books, although, for discussing the implications of those facts, books are very necessary.

As an example, the relative positions of places and regions can be learnt and recalled almost without effort from a map on which lines of longitude and latitude are marked ; while important trade and railway routes can be traced and easily understood from maps which indicate the relief of the land and the distribution of land and water.

Further, maps enable us to make a comparison between certain regions of the world, and they reveal quite clearly the relations between such geographical phenomena as relief and climate ; climate and vegetation or products ; products and population ; population and trade routes ; and routes and relief.

Definition and Varieties of Maps

A map, then, is a representation on a small scale of geographical phenomena. Usually the scale is so small that any attempt to show all the geographical features on one map would lead to confusion, and the map would be extremely difficult to read. Hence, it is customary for maps to represent only certain factors or certain features of the area or country concerned.

Maps which show only the coastline of a country are known as *outline* maps. If political units, towns, ports, rivers and railways are inserted they become what are called *political* maps. A *physical* or

orographical or *relief* map shows the nature of the surface of the land—differentiating clearly between the high land and the low land—and the courses of the chief rivers. A map showing the varying depths of the ocean is called a *bathymetric* map, and if physical features and ocean depths are both shown, we have what is called a *bathyorographical* map. A *vegetation* map, as its name implies, shows the distribution of the different types of vegetation. A map showing the distribution of vegetation, animals and races of mankind is termed a *biological* map, but if the distribution of the races of mankind alone is shown, the map is described as *ethnographical*. *Climatic* maps may show temperature, rainfall or wind, or a combination of more than one of these phenomena. *Economic* or *commercial* maps take a variety of forms, and graphically illustrate such factors as the conditions of production and trade, the centres of production of important commodities, the density of population and the direction of transport routes. *Geological* maps indicate the distribution of the various rocks and soils, whilst *astronomical* charts and maps depict the various geographical and astronomical phenomena of the universe.

Map Scales

Since a map is a representation on a small scale, we cannot use a map intelligently unless we understand what is meant by a " scale " and unless we can calculate actual distances and areas from measurements on the map.

When we say that a map is drawn to " scale ", we mean that any measurement on the map is a constant fraction of the actual magnitude which it represents. This constant fraction is the " scale " of the map. For example, if two points A and B are placed one inch apart on a map, and the actual distance between them on the earth's surface is one mile, the scale of the map is $\frac{1}{63,360}$, since there are 63,360 inches in a mile. Such a scale is always expressed as " one inch to the mile ", because this form of statement is easier to understand than the fraction form.

When some scale is shown which cannot be expressed as one inch to a simple number of miles or other units different from inches, the fractional form or the ratio form is used, all names of units being dropped : *e.g.*, 1/100,000 ; 1 : 100,000 ; or 1 to 100,000. This form is called the *Representative Fraction* (R.F.). Suppose the scale is shown as 1/100,000 or 1 : 100,000, *i.e.*, 1 inch represents 100,000 inches. Then to find the scale in inches to the mile, 63,360 must be divided by 100,000, and to find the *number of miles* represented by an inch on the map, 100,000 must be divided by 63,360. The results of these calculations show that the scale of 1 : 100,000 is approximately 0.63 inches to the mile or approximately 1·58 miles to the inch.

For convenience in measuring distances on maps, the scale of the map is usually drawn at one corner, and consists of a line marked off into convenient parts representative of distances. Thus, in Fig. 29, the scale of 1 : 4,000,000 represents a scale of, approximately, ·016 inches to the mile and 63·13 miles to the inch; the top line scale is divided into distances each representing 20 miles, whilst the lower scale is divided into distances representing 20 kilometres each.

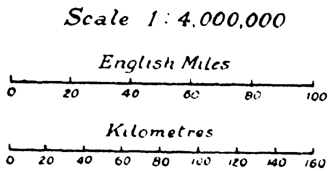


FIG. 29: MAP SCALE.

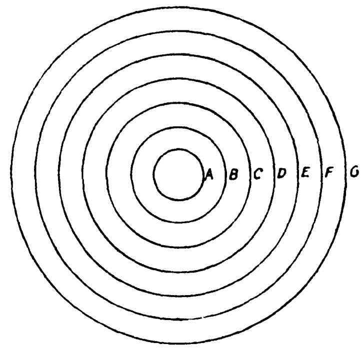


FIG. 30: "CONTOURS" OF FUNNEL.

Representation of Relief

It has already been mentioned that physical maps are used to indicate the variations in the height of the land. This could be done by embossing the face of the paper or cardboard, but clearly this is in most cases impracticable, and some other method of representing relief must therefore be used. The principal methods adopted are (1) Contours and form lines; (2) Spot heights; (3) Hachures; (4) Hill shading; (5) Layer tints.

Contours and Spot Heights

Contours are lines drawn on a map passing through all those points on the map situated at the same height above sea-level. Such lines are of value because they give the reader an idea of the nature of the surface of the region covered by the map. They show the high land and the low land, the steep slopes and the gentle slopes, the valleys and the ridges. It is thus possible, by studying a contour map of a region, to decide on the best route by which to cross the region. Large-scale contour maps are obviously of more value than small scale ones, as the latter cannot show so much detail.

The method by which contours are constructed may be illustrated by means of a simple experiment and diagrams. Assume that an

ordinary tin funnel, six inches long, with its pipe knocked off, is placed with its wide mouth resting on a table or on the ground, and that at intervals of one inch parallel lines are drawn with a piece of chalk round the funnel cup. Then if the funnel is looked at from above, the chalk lines and the top and bottom edges of the funnel will appear as shown in Fig. 30. *A* represents the top edge; *B* the ring five inches from the bottom; *C*, *D*, *E* and *F* the rings four, three, two and one inches respectively from the bottom; and *G* the bottom of the funnel which rests on the ground or table.

Now imagine the funnel as a hill 600 ft. high with a base of 450 ft., round the sides of which rings have been drawn at 100 ft. intervals. Then, if we made a drawing of the view from the top, we should get a result similar to that shown in Fig. 30. The lines which would mark the 100 ft. intervals would be *contour lines*, and may be defined as " the representation on a map of imaginary lines running along the surface of the earth at a uniform height above sea-level and at a given vertical interval apart ".

If we imagine that the hill is not circular in shape but that one side is steeper than the other, as in Fig. 31*a*, the lines as viewed from the top will appear closer together on the steep side than on the side with the more

FIG. 31*a*: SHAPE OF HILL.

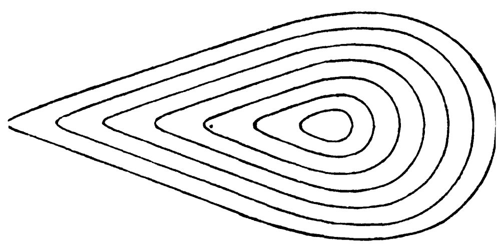


FIG. 31*b*: REGULAR CONTOURS FROM HILL.

gradual slope (Fig. 31*b*). This illustrates the very important fact that *where contour lines are close together they represent a steep slope, and where they are some distance apart they represent a more gradual slope.*

We must now proceed a step further, for no hills or mountains are found with such straight sides or with such even bases as that depicted above, and actual contours always appear on maps as *irregular* lines. Fig. 32*b* shows the contour lines of a hill shaped as in Fig. 32*a*.

The hill here illustrated is 500 ft. long and 200 ft. high. The contour lines are placed at 50 ft. intervals, and it will be observed that they lie closer together on one side than on the other, thus indicating that the hill has a gentle slope on one side and a steep incline on the other.

The figures 0, 50, 100, 150, 200 indicate the heights in feet represented

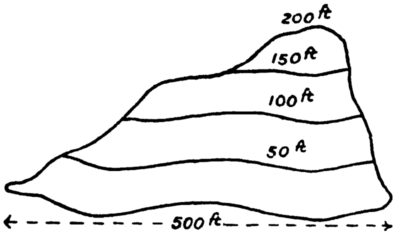


FIG. 32a: SHAPE OF HILL.

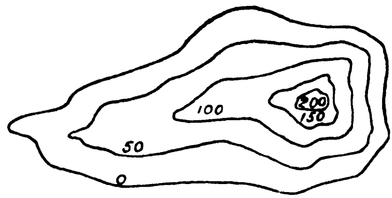


FIG. 32b: IRREGULAR CONTOURS FROM HILL.

by the contours. These figures, called *spot heights*, are used in conjunction with contours to enable the reader to judge which way the ground slopes. Thus, if the arrangement of the numbers in Fig. 32*b* were reversed, so that from the outer contour they read 200, 150, 100, 50, 0, the contour lines would represent a *depression* in the earth's surface instead of a hill. It is quite possible that at the bottom of this depression there would be a lake, probably with rivers flowing into it from the high surrounding land.

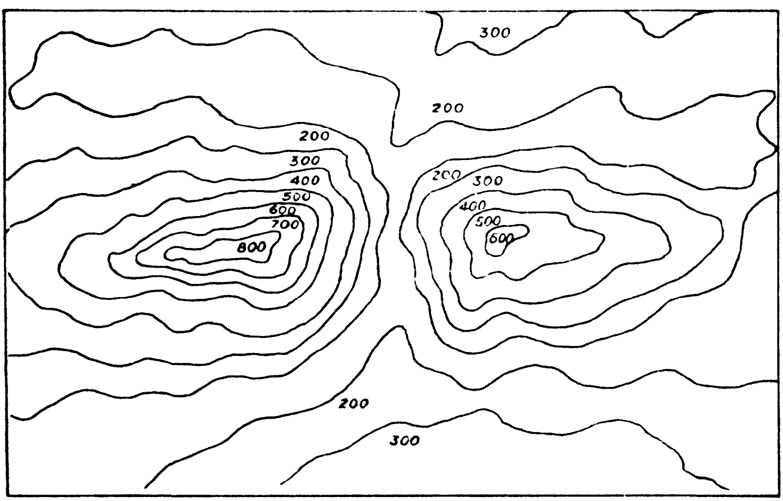


FIG. 33: PASS BETWEEN TWO HILLS.

The guiding rule is, therefore, that when the spacing of the contours, reading from high to low, *increases*, the slope is *concave* (that is, it dips inwards), and when the spacing of the contours, reading from high to low, *decreases*, the slope is *convex* (that is, it bulges outwards). Evenly spaced contours represent a *uniform* slope.

Fig. 33 shows a concave slope on the left and a convex slope on the right. In the centre the high land descends steeply to 200 ft. to form

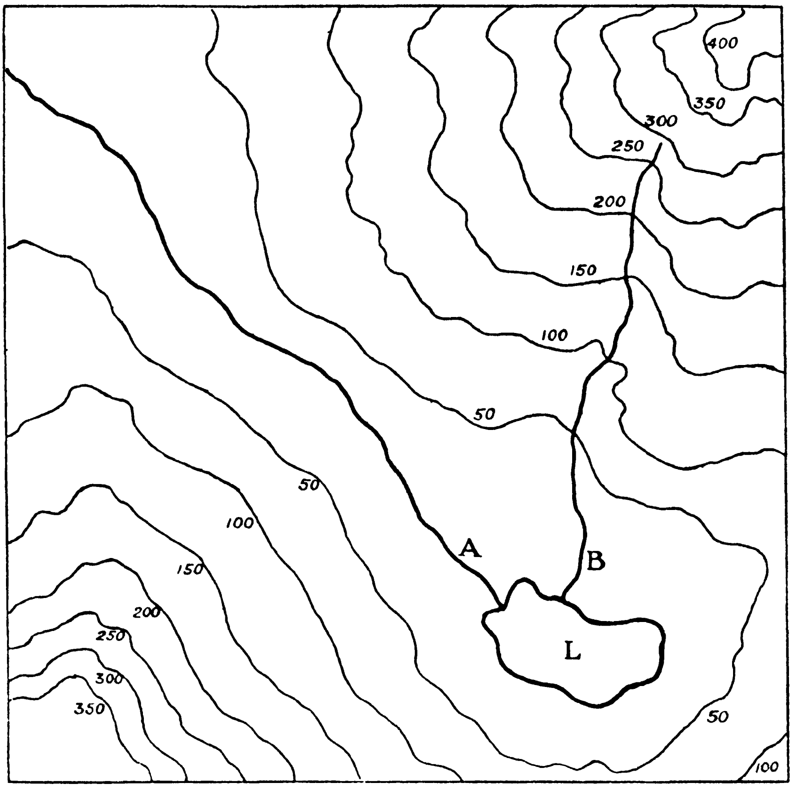


FIG. 34: LONGITUDINAL AND LATERAL VALLEYS.

a *pass* between the two hills. Fig. 34 shows two rivers, A and B (in thick lines), flowing into a lake, L, and from the contour lines we see that river A is flowing in a longitudinal valley between the two hills, whereas river B flows down from the side of a hill along a lateral valley. The lake is in a depression surrounded on three sides by the hills, which have a concave slope as the spacing of the contour lines increases from top to bottom.

With this information it is possible to construct a contour map from given data. For example: the physical features of a district consist of a river flowing in a southerly direction through a wide shallow valley, then cutting through a range of hills by a narrow gorge; the range runs east and west with a steep escarpment to the north and a gentle slope to the south; the height of the range is a little over 800 ft. with one conical peak rising to over 1,000 ft. It is required to draw a contour map of the district, inserting contour lines at intervals of 100 ft., the lowest at 200 ft. above sea-level. The result is shown in Fig. 35.

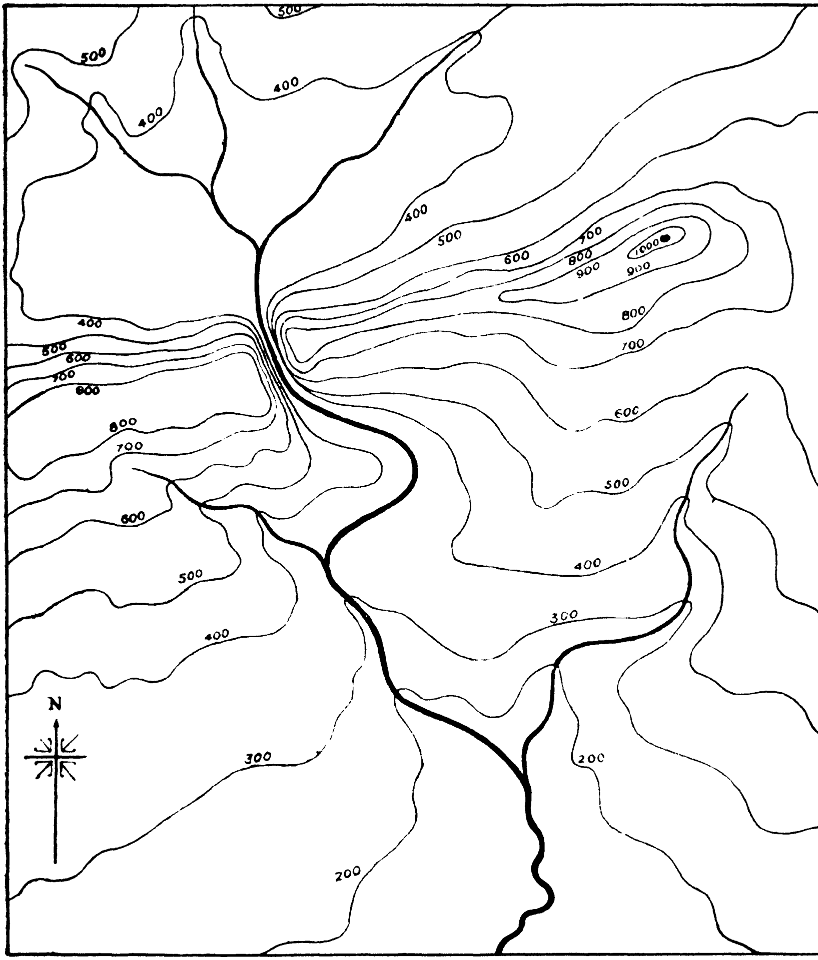


FIG. 35: CONTOUR MAP FROM GIVEN DATA.

Vertical Interval and Horizontal Equivalent

In studying contours it is necessary to understand two terms which are frequently used, viz., *Vertical Interval* (V.I.) and *Horizontal Equivalent* (H.E.) (see also p. 89). These terms are illustrated in Fig. 36, from which it will be seen that the former is the vertical distance between any two successive contour lines whereas the latter is the equivalent measured horizontally between any two similar lines.

On ordinary British maps the V.I. is constant for any given map

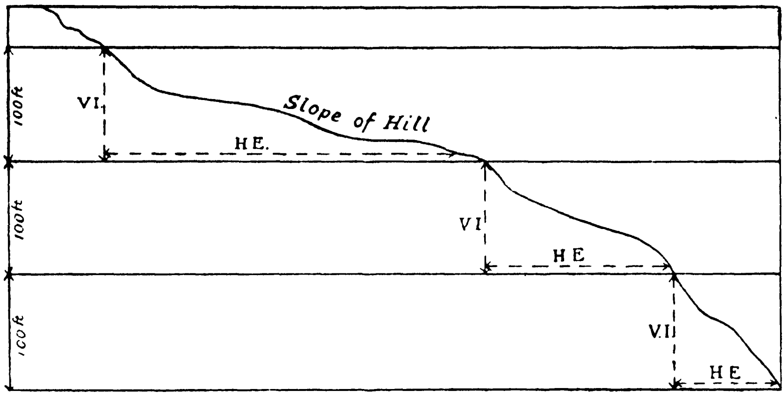


FIG. 36: VERTICAL INTERVAL AND HORIZONTAL EQUIVALENT.

and is stated in feet; for example, the V.I. in Figs. 32 and 34 is 50 ft. while in Fig. 33 it is 100 ft. The *horizontal* distance between two successive contour lines must vary, however, as it is comparatively small for steep slopes, and increases as the slopes become more gentle. In British maps the horizontal equivalent is always given in yards.

Sections

From this explanation of the meaning of contour lines and of vertical interval we should be able to construct a section of any hill or of any particular area. The definition of a section is " the *outline* of the intersection of the ground by a vertical plane ". Thus, if a pipe were cut through in a direction perpendicular to its length, it would appear in section as a circle with a circumference the same as that of the pipe.

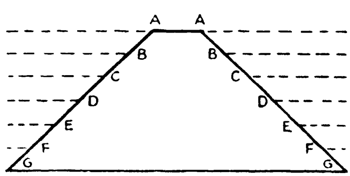


FIG. 37: SECTION FROM FIG. 30.

The same would apply to a funnel if it were cut in section parallel to the mouth, although, if it were cut from top to bottom, it would appear in section as a triangle with the vertex removed. The vertical section we should obtain from Fig. 30, for example, would be as shown in Fig. 37, where AA is the diameter of the circle A, BB the diameter of the circle B, and so on.

On this principle we can make a section across any contour map. Thus Fig. 38a shows how a section can be obtained across the area shown in Fig. 33. The section is taken along the line XY. The perpendicular dotted lines must be drawn from the point where each contour intersects

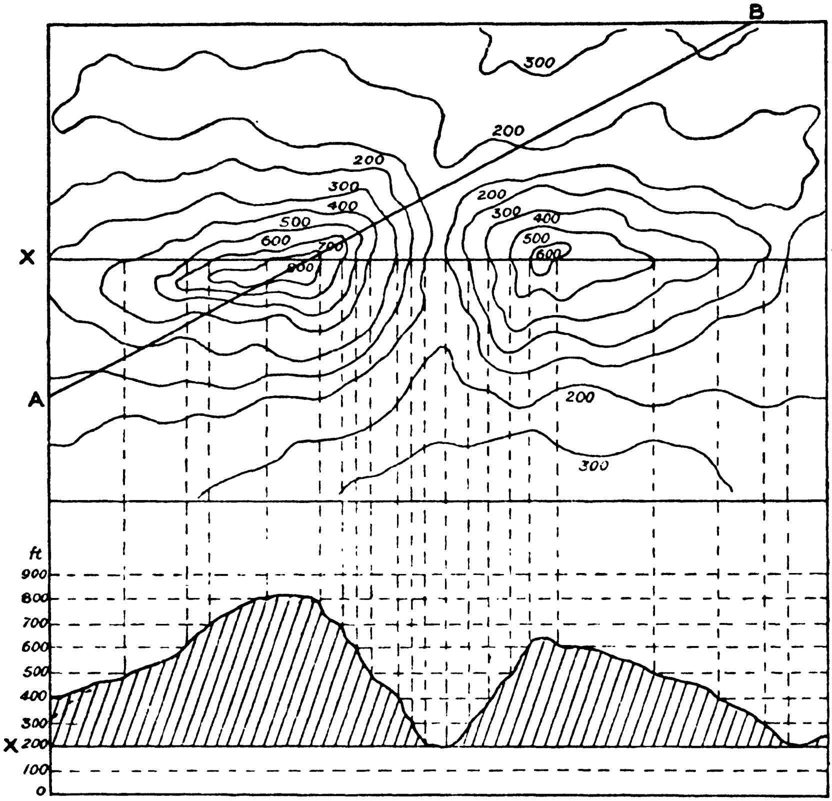


FIG 38a: SECTION ACROSS XY IN FIG. 33.

the line XY to the equivalent height marked off on the scale below as indicated on the outside perpendicular lines. The various points thus obtained are then joined together. It will be observed that the dotted upright lines illustrate quite clearly that where the slope is steep the contours are closer together than is the case where the slope is more gradual. Where a section is drawn it is usual to exaggerate the vertical scale so that the relief can be more clearly visualised.

It is sometimes necessary or more useful to make a section along a diagonal line on the map. The section is made in the same manner as before except that it is not correct merely to draw perpendicular dotted lines from the points where the diagonal is crossed by the contours. The diagonal line must be measured and reproduced and the points where the contour lines intersect the diagonal must be accurately marked on the reproduced diagonal line. This is best done by marking the intersections on a separate piece of paper and transferring them to the reproduced diagonal. Fig. 38b shows an accurate section along the line AB in Fig. 38a. Fig. 38c shows an *inaccurate* section along the same line. The

latter has been obtained merely by joining the intersecting points in the manner employed in Fig. 38*a*. When Fig. 38*c* is compared with Fig. 38*b*, it will be seen that the inaccurate section in Fig. 38*c* exaggerates the slopes by lessening the distance between A and B.

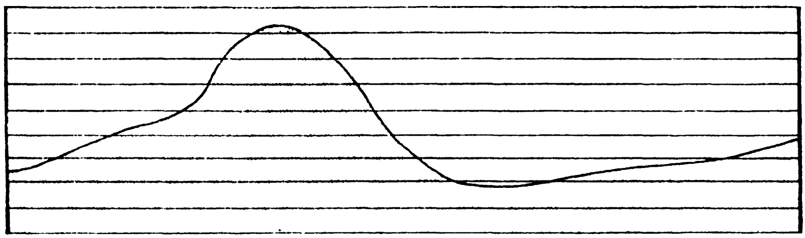


Fig. 38*b*: Accurate Section along A—B in Fig. 38*a*.

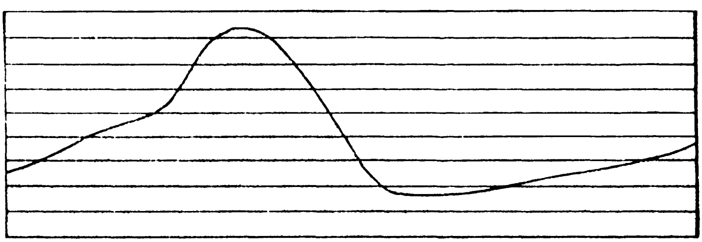


Fig. 38*c*: Inaccurate Section along A—B in Fig. 38*a*.

Visibility. It may be necessary to determine whether two places on a map are intervisible, *i.e.*, whether the one place can be seen from the other. This is frequently possible merely by an inspection of the map. If no higher land or obstructions such as buildings and trees obscure the view, the two places will be visible from each other. On a concave slope, summit and foot are intervisible; but on a convex slope they are not intervisible. Where visibility cannot be determined by inspection a section should be made between the points concerned. The sections in Figs. 38*a* and 38*b* show clearly that neither XY nor AB are intervisible; but a section from X to B in Fig. 38*a* will show that these two points are intervisible.

Alternative Methods of Representation

Form Lines may be termed approximate contours as they are not necessarily placed at regular intervals. They are therefore not so reliable as contours, although they show the lie of the ground in much the same manner.

Hachures indicate the nature of relief by lines drawn downwards in the direction where the slope is steepest. Gentle slopes are shown by fine lines drawn far apart, but as the slope increases the lines become

thicker and closer together. Thus, although the general lay of the land is shown quite clearly, the actual degree of the slope is not indicated, and, for this reason, hachures are not now used to any great extent.

HILL SHADING is similar to hachuring, but shading is utilised instead of line work. The heavier the shading, the greater the height.

LAYER TINTS show relief by variations in colour tints. The ground between successive contours is shown in different tints according to height, and darker tints are used as the height increases. This colouring gives the appearance of a model, and is most effective where the land varies considerably in height. The method has the disadvantage, however, that as the land between the contours is indicated by the same tint throughout, it appears to be level and any differences in its relief are not apparent.

Ordnance Survey Maps

The maps of areas in the British Isles issued by the Government are known as *Ordnance Survey Maps*. They are printed either in black and white or in colour, and are particularly good examples of the art of map making. Fig. 39 is a reproduced section of an Ordnance Survey Map drawn in black and white on a scale of 1 inch to 1 mile.

On these maps various objects, such as churches and bridges, which it is required to indicate, are represented by what are known as *conventional signs*.

These are used because there is insufficient space on the average map to show such objects in plan, or in their proper shape ; hence, the larger the scale of the map, the fewer conventional signs will be required. The conventional signs, or symbols, thus used on Ordnance Maps, together with the scale of the map, are usually shown in the bottom left-hand corner. It will, of course, be realised that Ordnance Maps can be obtained on larger scales than that on which Fig. 39 is based.

The contour interval in Fig. 39 is 100 ft., the lowest contour being at 200 ft. The River Test flows S.S.W. in a fairly wide valley between the 200 ft. contours and this valley has been followed by the railway and by the roads running north and south. The main road, however, runs east-west through Stockbridge. The steepest slope is east of Stockbridge, where the land rises to over 500 ft., and it will be seen that the two roads into Stockbridge from the east have avoided the steepest part of this slope, running north and south of the 500 ft. contour. Stockbridge is situated at the point where the main north-south and east-west routes converge. Longstock lies near the point where the river has been bridged and Leckford, as its name implies, arose where the river was sufficiently shallow to be forded—note the significance of the smithy (for shoeing horses, etc.) in this connection. The map

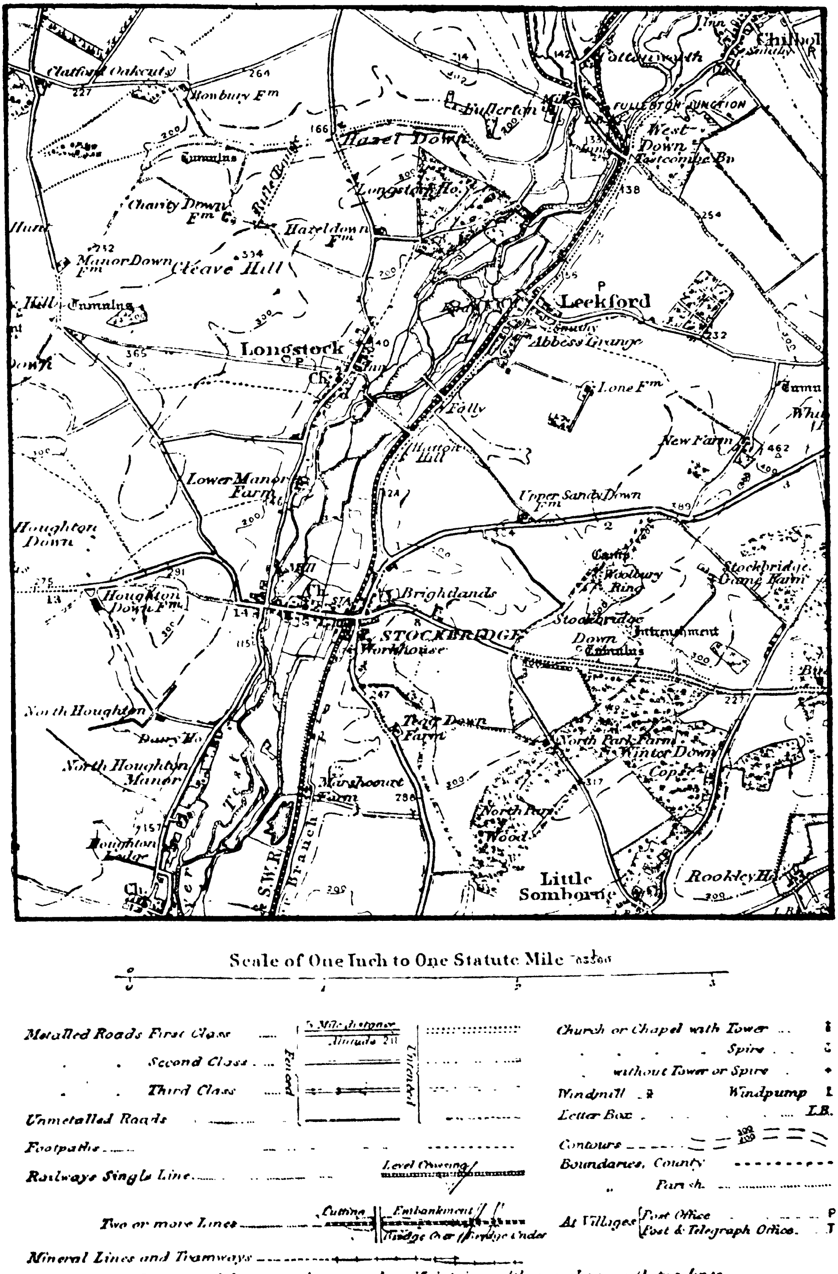


Fig. 39: Section of Ordnance Survey Map with Conventional Signs.
(Reproduced from Ordnance Survey Map with the sanction of the Controller of H.M. Stationery Office).

also shows quite clearly the wooded parts of the area represented, while features such as churches, windpumps and post offices are indicated by means of conventional signs.

ELEMENTARY SURVEY AND THE SIMPLER INSTRUMENTS

Chain Surveying

Before an ordnance map, or, indeed, any other map, of a given area can be accurately drawn, the area concerned must be carefully *surveyed*, *i.e.*, it must be measured and inspected by qualified surveyors, and notes must be made of such matters as the slope of the land, the direction of flow of the rivers, and the position of the various objects which are ordinarily represented by conventional signs.

In this country, measurements for surveying purposes are usually taken by the use of a metallic chain known as *Gunter's Chain.* This measures 22 yards, or one chain, in length, and is composed of 100 links, of which the two end ones have handles attached for convenience in use. The chain is a unit of length of great convenience for land surveying, since 1 square chain (484 sq. yards) is equal to $\frac{1}{10}$ of an acre. With each chain are provided ten metal arrows, pointed at the bottom for sticking into the ground during the surveying process, in the manner explained below. Gunter's chain is sometimes known as the "*short chain*", in contra-distinction to the so-called "*long chain*" of 100 ft.

Surveying by the use of the chain is very simple. Suppose the area to be surveyed is a field. First of all an outline of the field is drawn by the surveyor in his notebook, and each corner of this rough plan is indicated by a letter (see Fig. 40). The two extreme corners (A, C) are joined by a straight line which is then actually measured diagonally across the field and a note of the distance is recorded on the plan. Then, using this line as a base, the surveyors measure off perpendicular distances

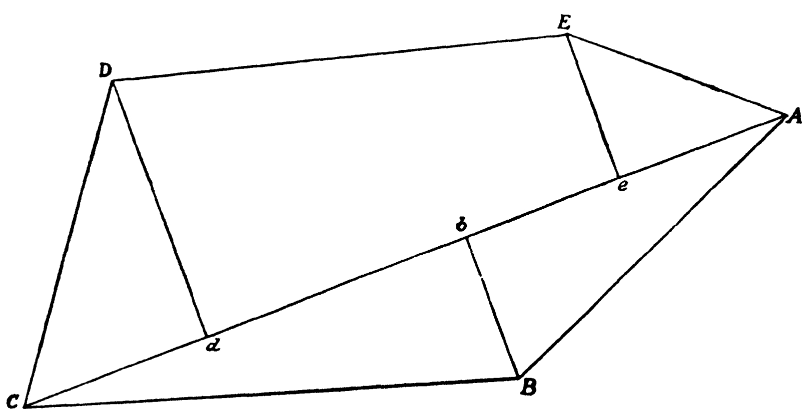


FIG. 40: DIAGRAM TO ILLUSTRATE CHAIN SURVEY.

to the remaining corners of the field (Bb, Dd, and Ee). These secondary measurements are termed " offsets ".

To measure any one of the distances, *e.g.*, A–C, one end of the chain is held by the " leader " and the other end by the " follower ". The follower stands at A and the leader walks towards C carrying the arrows with him. When the chain becomes taut, the leader turns and faces the follower, who then sees that he (the leader) is in a straight line with point C. The leader places his end of the chain on the ground, pulling it taut, and marks its position by inserting an arrow, or, if the ground is too hard, by making a mark and laying the arrow down. The follower then moves up to the arrow, which he collects, and the process is repeated until the leader reaches C. He pulls the chain taut and the number of links is counted from the last observation point, where the follower is standing, to C. The number of complete chains is indicated by the number of arrows in the follower's possession, and the length of the distance A–C having been thus ascertained in chains and links, it is recorded on the plan.

The position of *e* may be found by the use of an optical square or a cross staff, but it may be determined very simply as follows. The chain is run out from A as before. An ordinary camera tripod stand is taken, with a flat wooden top on which are ruled two lines accurately cutting each other at right angles. At the two extremities of each line pins are inserted vertically upright. The tripod is moved along the chain until it can be seen from observation that, whilst two of the pins are in line with both A and C, the other two are simultaneously in line with E. This gives the position of *e*, and the positions of *b* and *d* are obtained in a similar manner. All the distances are then measured in the way already explained, and the measurements are recorded on the rough plan.

The survey here briefly described is, of course, applicable only to small straight-edged fields. Where the hedges are curved or irregular, it is often necessary to take many offsets either from the original chain line or from other chain lines running from corner to corner round the field.

In plotting the plan from the rough sketch, the first matter for consideration is the scale to be used. In the case of a small field a suitable scale would be 1 inch to 200 links. When the scale has been determined, a suitable point on the plan is chosen for A and the line AC is measured out and marked in pencil. The positions *e*, *b* and *d* are then found and the offsets are measured off and marked in pencil to give the corners of the field. The outline can now be inked in, and it is usual to indicate the pencilled measurement lines either by dots or by lines of a colour different from that of the outline.

To the plan thus constructed, an arrow is usually added indicating the direction of North, in order that it may be seen how the area surveyed is situated in relation to the four cardinal points of the compass, *i.e.*,

north, south, east and west. The north point is in the direction of the North Pole and the south point in the direction of the South Pole. Facing north, the west point is midway between the Poles on the left-hand side and the east point midway between the Poles on the right-hand side. The majority of maps are drawn so that the top corresponds to the north, the bottom to the south, and the left and right-hand sides respectively to the west and east.

Setting the Plan

The indicator on the plan of the direction of North involves, first of all, the *setting* of the plan so that it corresponds exactly in direction with the area it illustrates. This is best done by pinning the plan to a drawing-board and placing it flat on the ground, or on a convenient support, at a suitable point in the area represented thereon, *e.g.*, at one corner of a field. A ruler is then placed, edge uppermost, along the line on the plan which joins the point corresponding to the position of the surveyor to one which indicates a distant corner of the field. The board is then rotated, pivoting on the surveyor's position, until the straight edge, as viewed by the surveyor's eye, points to the actual distant corner of the field. The plan is then said to be *set* and it remains to determine and to mark thereon the direction of the north point.

True and Magnetic North

The position of the North point can be determined in a number of ways, but for map-making purposes sufficient accuracy is obtainable by the use of an ordinary compass. It is not sufficient, however, merely to place a compass on the plan, when it has been set, and to mark the two extremities of the needle and join these points, marking the North point with an arrow head or star. Although we should thus obtain a North line, it would not be a geographical or *True* North line (*i.e.*, from Pole to Pole), for the compass needle is attracted to the *Magnetic North*, and therefore compass bearings are always magnetic bearings. So, in order to determine the True North point, the compass reading has to be adjusted by making an allowance for the *magnetic declination*, or, as it is also called, the *magnetic variation*, *i.e.*, the angle between the True North and the Magnetic North.

The Magnetic North is not a fixed point, but slowly changes its position from year to year. From the viewpoint of an observer in this country, it is at present west of the True North Pole which, however, it is gradually approaching, with the result that the magnetic variation is gradually lessening. Moreover, this variation is not the same for all places. There is, for example, a difference at present of about 5° in the variation as between the west and the east of the British Isles.

The magnetic variation can, however, be determined for any place at any time by reference to tables which are available. Once the variation is known for the particular place and time required, the True North may be marked on the plan after the latter has been set by marking the magnetic North with the aid of a ruler in the manner already indicated. Then, supposing the magnetic variation at the place to be 12°W., the true North is obtained by marking off with the end of a protractor an angle of 12° to the *east* of the magnetic North. The magnetic variation in England for the year 1938 was provisionally recorded as 11°W.

If the magnetic variation were *east* of True North, the angle would need to be marked off *west* of the Magnetic North. Thus, in order to find the true bearing of any place after having determined the magnetic bearing, it is necessary to *deduct* the magnetic variation if the variation is west of True North and to *add* the angle if the variation is east of True North. For example, supposing the magnetic variation to be 12°W. and a magnetic bearing of 120° is determined, then the true bearing is $120° - 12° = 108°$; and if the magnetic variation were 12°E., the true bearing of a magnetic bearing of 120° would be $120° + 12° = 132°$.

The Compass

The ordinary type of magnetic compass consists of a magnetised needle accurately balanced on a pivot, in a glass-covered case. The north pole of the needle is marked in some definite way, either by colour or shape, and the circumference of the base of the case is marked off in degrees up to 360°. The points of the circumference marked 360°, 270°, 180° and 90° are marked N., W., S. and E. respectively. A bearing is taken by holding the compass horizontally until the needle settles, when it may be taken to be pointing in the direction of the Magnetic North. The case is then rotated carefully until the graduation 360° comes directly under the north pole of the needle, and, when this occurs, the graduation on the line joining the pivot of the needle to the object under observation will give the magnetic bearing.

An improvement on this type is the ordinary card compass, with which the rotation of the compass case is unnecessary, as the entire face swings round. In the card compass the needle is affixed to the under side of a circular card, which is graduated in the same way as the bottom of the case in the ordinary compass. The 360° graduation is placed over the north pole of the needle, so that the bearing can be read as soon as the card comes to rest.

The Prismatic Compass

The prismatic compass is merely a card compass provided with accessories to enable the observer to view the distant object and to

read its bearing at the same time. With the ordinary types of compass it is very difficult to obtain accurate readings, since the position of the holder has to be altered between viewing the object across the top of the compass and reading the graduation, and the movement involved causes the needle to alter its position.

The card of the prismatic compass has two rows of graduation. The inner row is identical with that of an ordinary card compass, but the outer one differs from it by 180°—the North point being marked 180° and the South point 360°. In Fig. 41*a* most of the graduations have been omitted in the interests of clarity ; but it should make the reason for the arrangement quite clear. From the figure it will be seen that the magnetic bearing as read at A on the inner row and at B on the outer row is the same—40°. The prism (see Fig. 41*b*) fixed to the top of the

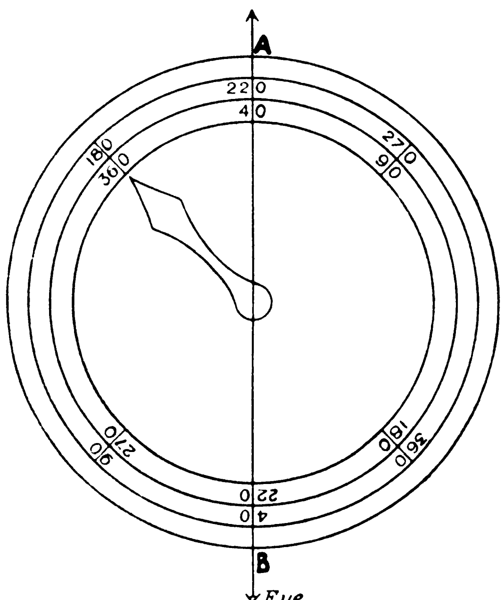


FIG. 41*a* : GRADUATIONS OF PRISMATIC COMPASS.

rim of the compass case immediately over B acts as a magnifying reflecting mirror, whereby the observer, although looking in a horizontal direction at the distant object, is enabled to read its graduation at B.

By the use of the prismatic compass, bearings can be taken with great accuracy. When an observation is to be made, the lid of the compass case is opened at right angles to the top of the case, as in Fig. 41*b*, and viewing the distant object, *e.g.*, a church steeple, through a slit in the middle of the face of the prism, the observer aligns on the object a hair line marked on a glass window in the lid of the case, and, at

the same time, reads the graduation through the prism. The view thus obtained through the slit and the prism will be as shown in Fig. 41c.

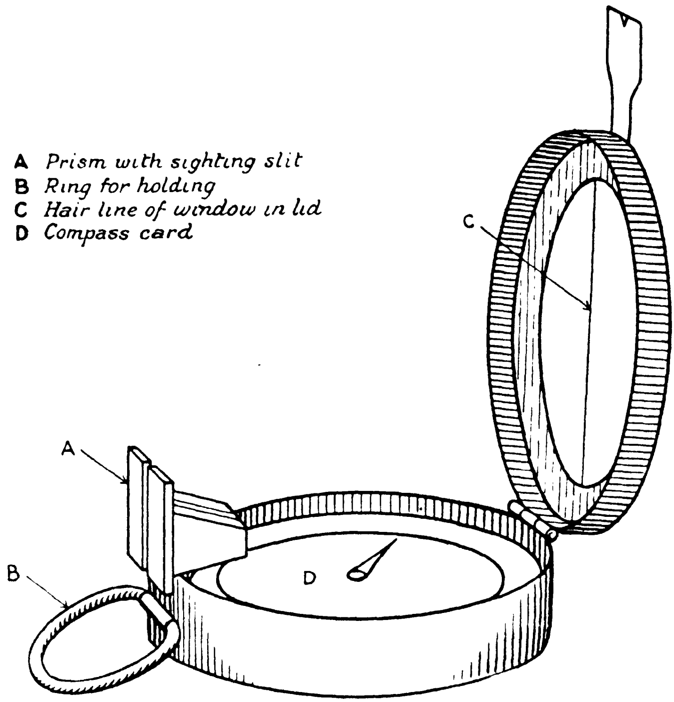


FIG. 41b: PRISMATIC COMPASS OPEN READY FOR USE.

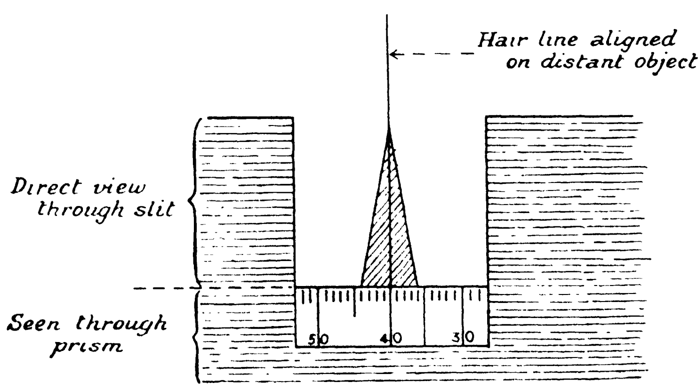


FIG. 41c: VIEW THROUGH PRISM AND SIGHTING SLIT OF PRISMATIC COMPASS.

Plotting Bearings

To " plot a bearing " means to fix on a map or plan the position of a distant object corresponding to a given bearing. Suppose that in the

field surveyed by means of the chain (p. 80) there is a tree, the position of which you wish to mark on the plan. Standing at one of the fixed points—say D—you take a magnetic bearing of the tree with the prismatic compass. Suppose it to be 130°. The magnetic variation being taken as 12°W., this gives a true bearing of 118°.

Place a protractor on the plan with its centre mark at D and its edge lying along a true North and South line drawn through D; mark the paper at the 118° graduation; remove the protractor and draw in pencil a line from D through this point; repeat this process from one of the other fixed points in the outline of the field—say E. The intersection of the lines thus drawn will give the exact position of the tree. By this process, known as *intersection*, the unknown position of a distant object can always be found from two known positions of the observer.

When this method is employed for survey purposes, it is called *triangulation*, and in this case a base line, such as that given by DE in the above example, is taken, and from it the positions of several distant points are fixed by intersection. The figures resulting from the plotting of the bearings taken are, of course, triangles constructed on this base. Further observations are made from the points so fixed and the positions of other objects are located. In this way the whole of the area under survey can be mapped out. When a large-scale survey is being made it is necessary to make an allowance for the curvature of the earth because in such cases the triangles represent spherical sections of the earth's surface.

Occasionally, the surveyor finds that, instead of being at some point already fixed, he does not know his position and must accordingly determine it on his plan. If three points whose position he knows are within sight, he can do this by the process known as *resection*, which can be illustrated as follows: Lay a ruler on a piece of tracing paper attached to a board. Take any point on the paper as a pivot and draw a line along the straight edge of the ruler in the direction of each of three known distant points. Remove the paper from the board and place it on the map so that the three lines pass through the three known points, as marked on the map; the pivot point marks the position required and can be pricked through on the map.

Up to now we have dealt only with what are known as "forward" bearings or bearings taken forward from the observer to a distant object. The bearing from a distant object to the observer can, however, be determined, and this is called a "back" bearing. If the forward bearing is less than 180°, the back bearing is found by *adding* 180°. If the forward bearing is greater than 180°, the back bearing is found by *subtracting* 180°. For example, if the forward bearing is 140°, the back bearing is 140° + 180° = 320°; and if the forward bearing is 190°, the back bearing is 190° − 180° = 10°. As in the case of forward bearings, allowance must be made for the magnetic variation.

In both intersection and resection the angle made by the two lines should approximate as nearly as possible to 90°, as the liability to error in fixing the point is thus much less than where the angle is acute or obtuse. This fact must be borne in mind in fixing the points from which (in the case of intersection) and to which (in the case of resection) the observations are made.

Traversing

" Traversing " consists in taking a series of forward bearings and at the same time measuring the distance between the points from which the bearings are taken. When the traverse is " closed " (*i.e.*, when the operation is concerned with the outline of an enclosed area, such as a field) its accuracy can easily be checked, for the plan constructed should form a completely enclosed figure ; *i.e.*, the last bearing, known in a closed traverse as the " closing " angle, should pass exactly through the starting point.

In surveying for map-making, traversing would never be used in place of triangulation, unless the country is such that triangulation is impossible. In flat and thickly wooded country and in large towns, however, traversing is frequently resorted to, either to form the complete framework or merely to link up and provide the detail between two of the fixed points (known as *trigonometrical stations*) forming the apices of the triangles in a triangulation survey. Again, in cases where a road or river, and not a whole area, has to be surveyed, traversing is the best method to adopt. A bearing is taken of the road or river for as long a distance as it remains approximately straight. The distance is then measured to the point on which the bearing was taken, and a back bearing is taken on the starting point to check the accuracy of the forward bearing. This process is repeated for each approximately straight stretch, the bearings and distances being recorded in a note-book for plotting when the survey is complete. In the case of broad curves, bearings can be taken across country to distant points on the road or river and the windings can then be put in by measured offsets.

The traverse can be completed from the note-book with the aid of a protractor. For example, the length and magnetic bearings of four approximately straight consecutive stretches of a road are :—

From	A–B :	110 yards,	forward	bearing	208°,	back	bearing	28°
,,	B–C :	30 yards,	,,	,,	141°,	,,	,,	321°
,,	C–D :	60 yards,	,,	,,	96°,	,,	,,	276°
,,	D–E :	80 yards,	,,	,,	155°,	,,	,,	335°

The magnetic variation is 13°W.

To find the true bearings, it is necessary to deduct the magnetic variation from the given forward bearings because the variation is west

of true north. A plotted traverse of the bearings, on a scale of 300 ft. to one inch, will appear as shown in Fig. 42.

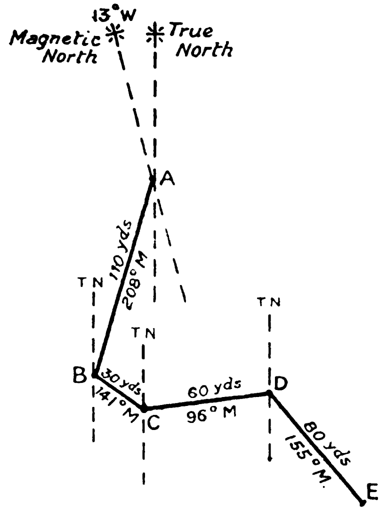


FIG. 42 : TRAVERSE.

The Plane Table

A plane table is a device which enables most of the operations described above in connection with the prismatic compass to be carried out more accurately. Its great drawback is that it is an inconvenient " piece of furniture " to carry about, whereas the chief advantage of the prismatic compass is its portability.

The plane table is simply a portable table, the top of which can be revolved or tightly screwed up in any position in the horizontal plane. It stands on a firm tripod about four feet in height and is provided with two accessories—a *Sighting Rule*, or *Alidade*, and a *Box-compass*. The *alidade* is merely a boxwood rule, with bevelled edges marked with various scales, fitted at each end with folding metal sights. The *box compass*, or *trough compass*, consists of a magnetic needle about 5 inches long fitted on a pivot in a metal trough, the whole being encased in an oblong wooden box having true parallel sides. At each end of the box are short arcs graduated to show 10 or 20 degrees.

A complete survey of a limited area can be made by means of a plane table, without other instrumental aid. Indeed, it is unique among surveying instruments in that it enables a surveyor to draw a complete map without measuring any angles or doing any numerical work, except in contouring. Moreover, it is particularly valuable for supplying the detail of an area which has already been triangulated. In this respect, after the table has been covered smoothly with a sheet of drawing-paper

on which the trigonometrical points are marked, it is set up accurately at one of these points. The screw which fixes the top of the table is then loosened and the alidade is placed on the paper with one edge exactly on the line joining the operator's position on the plan with another of the fixed points. With his eye close to the sighting aperture of the alidade, the observer then slowly turns the top of the table until the sighting vane of the alidade is aligned on the distant station. The table is then firmly clamped in this position, and the box-compass is placed on the paper and moved round till the needle points to zero. Two lines are then drawn, one on each side of the box, so that the table may be set by the compass at this point on any future occasion. It is now ready for filling in the detail of the country in the neighbourhood of the point at which it is placed.

The surrounding country is carefully examined for outstanding objects (such as isolated trees, chimney-pots and sign posts) which present much the same appearance from all angles, and which will, therefore, admit of accurate intersection. The alidade is carefully aligned on these objects in turn, rays being lightly drawn in pencil from the observer's position on the plan towards the estimated position of each. By each ray is written the name of the object on to which it has been taken, so that when the table is moved to other trigonometrical stations, it can readily be seen to which objects the rays refer. The detail in the vicinity of the station is now drawn in, the direction taken by roads, hedges and similar features being indicated by short rays. The plane table is set up at each of the other trigonometrical stations as they are reached in the process of filling in the detail, and the position of the various outstanding features is fixed by the intersecting of the rays drawn from the various stations.

The Clinometer

In an ordinary survey, the position of contour lines may be determined by the use of a *clinometer*, which is an instrument for the measurement of vertical angles. Although there are several patterns in use, all are the same in principle. Either by means of a plumb weight or a spirit level, the zero line of a scale of degrees is kept horizontal or the indicator is kept vertical. The observer directs the line of sight of the instrument on to the point whose angle of elevation or depression he wishes to measure, and he obtains the required angle by reading the difference in degrees between the line of sight and the zero line.

In contouring, it is first necessary to decide the vertical interval at which the contours are to be shown—with a fixed V.I., the horizontal equivalent will vary according to the degree of slope. Secondly a "scale of slopes" must be constructed. For a slope of 1° a V.I. of one foot corresponds to an H.E. of 19·1 yards, but since 19·1 is rather an awkward figure for purposes of calculation, it is usual to take this figure

as 20. Taking S to represent the degrees of slope, the relationship can be expressed by the following formula :—

$$H.E. = \frac{20 \times V.I.}{S}$$

If, therefore, any two of the quantities H.E., V.I., and S are known, the third can always be found from the formula. Consider the following example :—

It is found by using the clinometer that a large stretch of moorland has a continuous slope of 8°. The contour lines have to be drawn at a V.I. of 100 ft. How far apart should they be drawn on the plan ?

$$H.E. = \frac{20 \times 100}{8}$$
$$= 250 \text{ yards.}$$

As far as the slope remains constant at 8°, therefore, the lines would be drawn at distances representing every 250 yards.

In this way the H.E. can be found for any degree. When this has been done, a scale of slopes can be constructed by simply drawing a straight line and marking off on it, to the scale to which the map is being drawn, the lengths thus obtained, numbering the divisions 1°, 2°, 3°, etc., respectively.

To construct a contour of a small hill by the use of a clinometer, the first contour line should be established just below the summit at a distance less than the V.I. selected. A point on the hillside should be marked at this height and from it a line should be completely levelled round the hill. This is done by fastening a piece of white paper or cloth to a stick at the height of the observer's eye from the ground. The clinometer reading is kept at zero, and sufficient points are fixed by sighting on the white mark, which is moved about as required. The position of this initial contour is then marked on the plan. The various spurs and valleys along the degree of slope to be measured are then marked on the plan by rays, the sketch being " set " on each in turn at the initial contour line, or bearings are taken with the prismatic compass and plotted with the protractor.

The degree of slope is carefully measured down each of the spurs and valleys, minor undulations being ignored. In this process the instrument must be kept close to the ground unless there is a suitable object, such as a bush or post, about the height of the observer, when the latter can use the clinometer in a standing position and make his observation to the top of the chosen object. When this has been done, the " scale of slopes " is consulted and the position of each contour line is marked on the plan where it crosses the rays. When the position of all the contours has been fixed in this way, the work is usually checked by levelling the whole area again at a point some distance from the initial contour. This will also give the exact shape of another contour line and will enable the

contours between it and the initial contour to be completed freehand from a careful study of the nature of the ground.

The plan is completed by neatly drawing the contour lines in red ink, and inserting the spot heights, care being exercised to ensure that the spot heights are placed *on that side of the contour line on which the ground is rising.*

QUESTIONS ON CHAPTER 4

1. Describe a method by which you could make a map of a small park or recreation ground. Draw a diagram to illustrate the answer. (*C.S., May*, 1927)

2. How is relief indicated on maps? Describe any *one* method by which the varying relief of a road can be determined for the purpose of map-making. (*C.S., Dec.*, 1926)

3. Draw a square with sides of six inches to represent the boundaries of a district and within it insert the following features, using a scale of half-an-inch to the mile.

   A range of hills, rising to 500 feet, runs from the south-west corner to the north-east corner of the map; 5 miles from the south-west corner the range is broken by a gap. A river *A* flows from the north-west corner of the map to the south-east corner, passing through the gap; before it enters the gap it is joined by a stream *B*, which rises among the hills in the north-east corner. A town *X* is situated 6 miles north of the south-east corner; there is a village *Y* north-west of *X*, on the stream *B*.

   Mark in red the probable course of a road from *X* to *Y*. State the distance in miles from *X* to *Y* in a straight line. (*C.S., Dec.*, 1929)

4. Using a scale of one inch to the mile and contour intervals of 100 feet, draw a contour map of an island six miles from east to west and four miles wide from north to south. Show a hill in the centre of the island 550 feet high rising steeply on the west and sloping gently towards the east. Draw a section through the centre of the island from west to east, using ¼ inch for every 100 feet of height. (*C.S.*, Nov., 1931)

5. An island is nine miles long from north to south and six miles broad from east to west. In the interior of the island are two hills 430 feet and 320 feet high; the hill-tops are four and a half miles apart and between them, near the middle of the island, the land is 140 feet above sea-level.

   Using a scale of two inches for three miles, draw a sketch of the island, mark the two hill-tops and insert contours at intervals of one hundred feet to show the configuration of the island. The contours must be numbered and the points of the compass must be indicated. (*C.S., March*, 1927)

6. In one and the same contoured sketch-map, combine at least the following features: Wide estuary of meandering river; ridge over 6 ft. high with long spurs; low coastal plain with sand dunes; plateau edge much dissected and exceeding 700 ft. in altitude; precipitous sea cliffs over 300 ft. high; roads; railways; deep gorge with swiftly-flowing river; three unequally sized settlements two of which are 12 miles apart and lie N.E. and S.W. of one another. The

sketch, complete with compass points, scale of miles and a key to all symbols used, should occupy approximately half a page. (*C.S., April*, 1937)

7. Show by means of a contoured sketch map, filling approximately half a page, the following: a mass of high land reaches 1,010 ft. and is separated by a steep-sided pass, 600 ft. high, from a hill mass (860 ft. summit) lying south of it. Flanking these uplands on the east and west are wide river valleys, below 250 ft.; the headstreams of the rivers are in the south of the area on the northern edge of a broken plateau of a general altitude of 700 ft. Contour interval 250 ft. Scale 1 in. to 1 mile.

   Draw a section to show the chief features cut by a north to south line through the highest point. (*C.S., Jan.*, 1931)

8. What is a plane-table? Explain fully how you would use a plane-table to make a sketch-map of a small area. (*C.S., Oct.*, 1928)

9. Using contours, or hachures, or both, make sketches illustrating—

   (*a*) river capture,

   (*b*) a fjord coast,

   (*c*) a waterfall in a country developed on very slightly dipping sedimentaries of varying resistance to erosion. (*C.S., April*, 1931)

10. Describe a prismatic compass, and explain how it is used. The table below is of bearings taken on a compass traverse, the magnetic declination being 14°E. Find the forward bearings from true North, and plot the traverse, on a scale of 100 feet to an inch. Suggest possible reasons for any irregularity noticed.

Line	*Length (feet)*	*Forward*	*Back*
AB	184	208°	28°
BC	310	160°	345°
CD	253	80°	255°
DE	207	184°	4°

   (*C.S., April*, 1931)

11. You wish to make a survey of a winding lane connecting two high-roads. Give an illustrated account of the method you would adopt. (*C.S., April*, 1930)

12. Using a suitable scale draw a map having an area of 150 sq. miles. By means of contour lines at suitable intervals represent the following features: -A mountain range runs from S.W. to N.E., rises to a height of 2,050 ft., slopes steeply to the S.E. and more gently to the N.W. A stream rising on the N.W. slope runs N.W. into the sea after crossing a plain. Along the coast are sea cliffs over 100 ft. in height. Make a section which will best show the character of the country. (*L.M., Jan.*, 1931)

13. How would an ordinary half-inch Ordnance Survey map be of assistance to an aeroplane pilot in guiding him over a district previously unknown to him? What actual features would he be able to recognise (*a*) more easily, and (*b*) less easily, from this map than would a road motorist? (*L.M., June*, 1929)

14. Write short descriptions of (*a*) the prismatic compass, (*b*) the clinometer. Show how you would use them in the survey of a small region with hill and plain intermingled. (*C.S., April*, 1935)

CHAPTER 5

MAP PROJECTIONS

If you look through an ordinary atlas or at a group of maps you will see that maps are constructed in many different ways. In some the lines of latitude and longitude are all straight lines. In others, the parallels are straight and the meridians are curved, or *vice versa* ; in others, again, the lines are not at equal distances apart. You will see, too, that as a result of this, the land masses in one map are of a shape markedly different from their shape in another.

These differences between maps arise because the earth is a sphere, and because, in mapping any area of the earth's surface, great difficulty arises from the impossibility of accurately representing a spherical surface on a plane. You can easily appreciate this difficulty if you attempt to wrap a piece of paper evenly around a ball. The sheet of paper will have to be creased and folded and will fit the ball fairly well only over a very small part of its surface.

Look at the matter in another way and imagine that the ball is closely covered by a very elastic skin. You will see then that, if you take the skin off the ball and flatten it, some points on the skin will not be stretched at all while others will have to be stretched enormously in all directions. Hence the resulting plane representation of the surface of the ball will be unequally distorted.

Maps can, of course, be made on spherical surfaces, and the foregoing difficulties of distortion can be thereby avoided ; but, whilst globes have many advantages over flat maps, they have to be very large for any detailed work, and they are extremely inconvenient for ordinary use because they cannot be kept compactly or transported easily.

The problem of representing the surface of the earth on a flat surface is simplified by considering only the lines of latitude and longitude ; for once a reasonable number of these have been projected according to some conventional scheme, the required details can be filled in easily. For this purpose, therefore, various conventions have been adopted, each of which involves distortion of a kind or in a direction different from the others. One, for example, will show some or all of the land masses out of shape (or distorted), while on another they will appear correct in shape but incorrect in area. It is, in fact, impossible to project a map of the world on to a plane surface so that it shows all the land masses correctly shaped *and* correctly proportioned—either the shape or the area,

or in some cases both, will be incorrect in some part of the map. Various methods of projection have been devised, however, whereby the errors have been reduced to a minimum, and the one selected for use in any particular case is chosen according to the purpose which the map is intended to serve, *i.e.*, so that the inevitable distortion of shape or of size is unimportant for the purpose in view.

" In choosing our system of map projection, therefore, we must decide whether we want :—

" (1) To keep the areas directly comparable all over the map at the expense of the correct shapes (*equal-area* projection) ; or

" (2) To keep the shape of the smaller geographical features—capes, bays, lakes, etc.—correct at the expense of a changing scale all over the map (*orthomorphic* projection) and with the knowledge that large tracts of country will not preserve their shape ; or

" (3) To make a compromise between these two conditions so as to minimise the errors when both shape and area are taken into account " . . . . or

" (4) To preserve the correct directions of all lines drawn from the centre of the map (*azimuthal* projection)." [1]

Some of the most important and most commonly used of the map projections are described below, but there are many others.

Mercator's Projection

Maps prepared on the well-known Mercator's projection represent the earth as a rectangle (Fig. 43). All meridians are shown as parallel straight lines instead of as halves of circles meeting at the Poles, as is the case on a globe. The parallels of latitude also are shown as straight lines parallel to the Equator, but, instead of being equally spaced, they are shown as getting farther apart as they approach the Poles, while the North and South Poles, which on the earth's surface are really points, appear as lines as long as the Equator. As this distortion at the Poles is so great on a Mercator's map, areas above lat. 80°N. or S. are rarely, if ever, shown thereon.

Obviously, this great distortion of areas far from the Equator is a marked defect of this projection. The scale is a changing one, and the areas are expanded more and more the farther away they are from the Equator. As, however, longitudinal expansion is always accompanied by a proportionate latitudinal expansion (*i.e.*, expansion east–west is balanced by a corresponding expansion north–south) *local* shapes are preserved. Large bodies of land and water are, however, greatly distorted as a whole. In a map of the world on Mercator's projection,

[1] M. Garnett, *A Little Book on Map Projection.*

Siberia and Alaska appear at least four times their actual size, and Greenland appears slightly larger than South America, whereas in reality it is only about one-tenth the size of that continent.

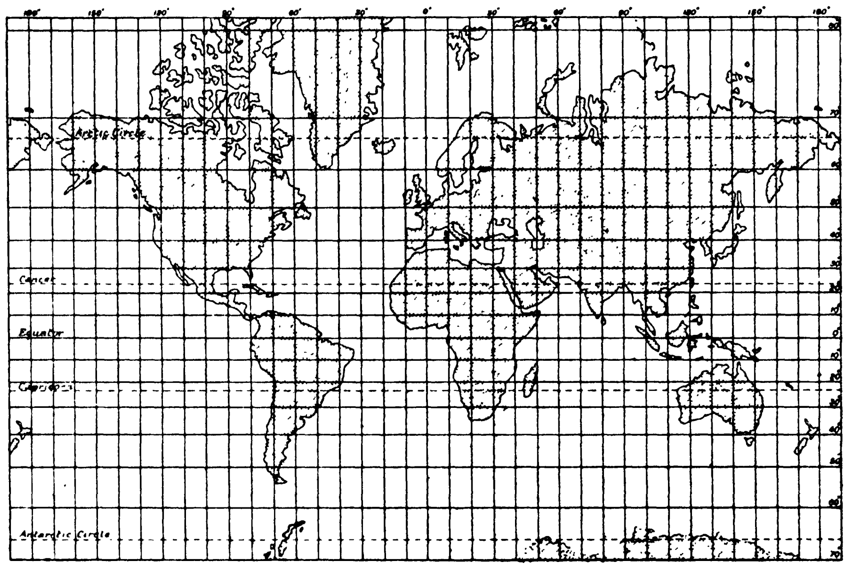


FIG. 43 : MERCATOR'S PROJECTION.

As, however, the map is made up of right angles, all bearings are true, and, consequently, the value of this projection lies in its great use for navigation and for representing climatic facts. A straight line joining any two points on a Mercator's map is a line of constant bearing, although, as will be explained later, it is only along the Equator and the meridians that a straight line on a Mercator's map represents the shortest distance between any such two points. Maps of the British Empire are usually shown on Mercator's projection, and in such cases, the countries in the higher latitudes appear large, for the reasons just given.

Mollweide's Projection

A map of the globe drawn on this projection takes the form of an ellipse and resembles an egg lying on its side (Fig. 44). The central meridian is shown as half the length of the Equator and at right angles to it, whilst the remaining parallels decrease in length in the higher latitudes, and this is in fact correct. The distance between successive parallels of latitude, however, instead of remaining constant, decreases slightly as the Poles are approached. The central meridian is a straight line, whilst the remaining meridians are curved, but instead of being the half of a circle as on a globe, the curve becomes more pronounced

as the meridians recede from the central meridian, and the marginal meridians are consequently greatly misrepresented.

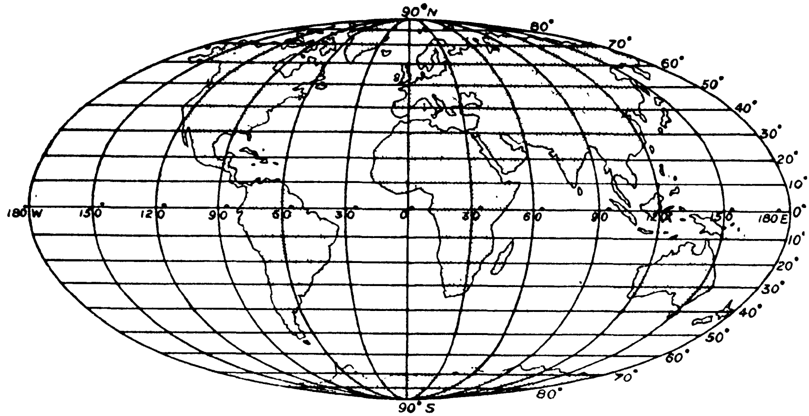


FIG. 44: MOLLWEIDE'S PROJECTION.

In a map of the world on this projection, the meridians halfway between the central and marginal meridian (90° in Fig. 44) form a circle. It follows that this projection has a vertical expansion and a horizontal contraction near the Equator, but a vertical contraction and a horizontal expansion near the Poles. The map is therefore *equal-area*, *i.e.*, all areas thereon are truly represented (*cf.* Greenland and South America), but, while Europe and Africa in the centre of the map preserve their shape, Australia and North America, being on the margins, are distorted.

This projection is in great use for showing the true superficial distribution of vegetation or other natural phenomena, either for the whole world or for smaller areas. But as maps drawn on this projection, unlike those drawn on Mercator's projection, are not true as regards distances, they are not suitable for showing the direction of winds and ocean currents, or for navigation purposes.

Sanson-Flamsteed Projection

The Sanson-Flamsteed Sinusoidal projection (or, as it is sometimes called, the Sinusoidal projection) is, like the Mollweide, an equal-area projection. It differs from Mollweide's projection, however, in that the parallels of latitude thereon are spaced apart at equal distances, while the Poles appear as points instead of smoothly curved surfaces. The central meridian is straight, whilst the remainder are curved and meet at the Poles, but the meridians midway between the central and marginal meridians (90° in Fig. 45) do not form a circle as they do in Mollweide's projection. The two projections are similar, also, in that the meridians cut the Equator at equal distances and that they fall nearer together as they approach the Poles.

On this projection all the land masses are distorted in shape, and this is particularly noticeable on the outer margins. Consequently, this

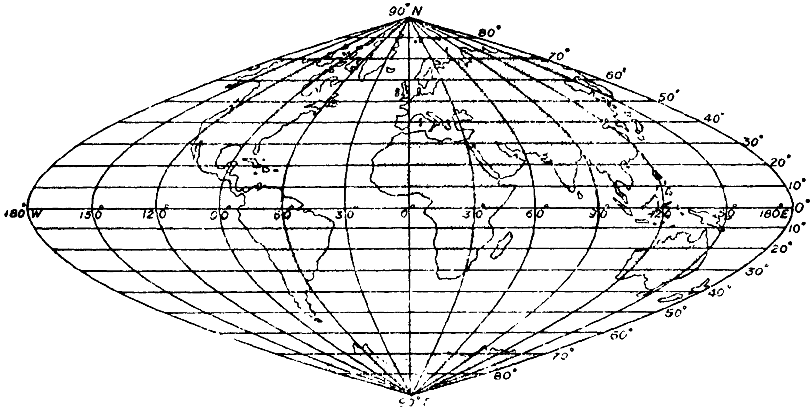


FIG. 45 : SANSON-FLAMSTEED PROJECTION.

projection is little used for maps of the world, but is reserved rather for the mapping of countries situated near the Equator, where the distortion is relatively slight and the areas practically correct. Maps of South America and of Africa are often shown on a sinusoidal projection, and, in such cases, the meridian which passes through the centre of the country is shown as a straight line, whilst the other meridians, including that of Greenwich, are slightly curved.

Hemispherical Projections

As the name suggests, this type of projection is used for showing the world in hemispheres. The principal types of this projection are the *Orthographic* projection, the *Stereographic* or *Azimuthal Orthomorphic* projection, and the *Zenithal Equal-area* projection. The last named is known more generally as *Lambert's Zenithal Equal-area* or *Lambert's Azimuthal Equivalent* projection, and is the most commonly used of the hemispherical projections.

In all hemispherical projections, the map is supposed to represent the view an observer would obtain of an area on the earth's surface if the latter were outlined on a transparent globe (Fig. 46). Projections of this type differ owing to the varying situations of the observer. In the *Orthographic* projection, the observer is supposed to be situated at an

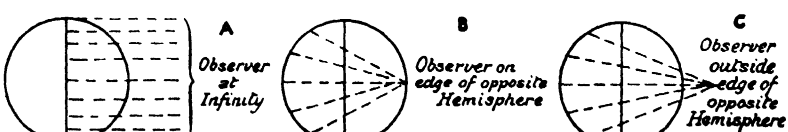


FIG. 46 : PRINCIPLES OF HEMISPHERICAL PROJECTIONS.

infinite distance from the globe (Fig. 46A), when the lines of latitude would appear to him to be parallel *straight* lines (Fig. 47), closer together towards the Poles than at the Equator. Along the Equator the meridians would appear farther apart in the centre, coming nearer together east and west, and all converging at the Poles. The projection is not therefore true for areas, directions, shapes or distances, except for a small part in the centre.

In the *Stereographic* and *Zenithal* projections (Figs. 48 and 49), the observer is supposed to be much nearer—on the opposite inner side of the globe in the first case (Fig. 46B) and just outside the opposite side of the globe in the second (Fig. 46C).

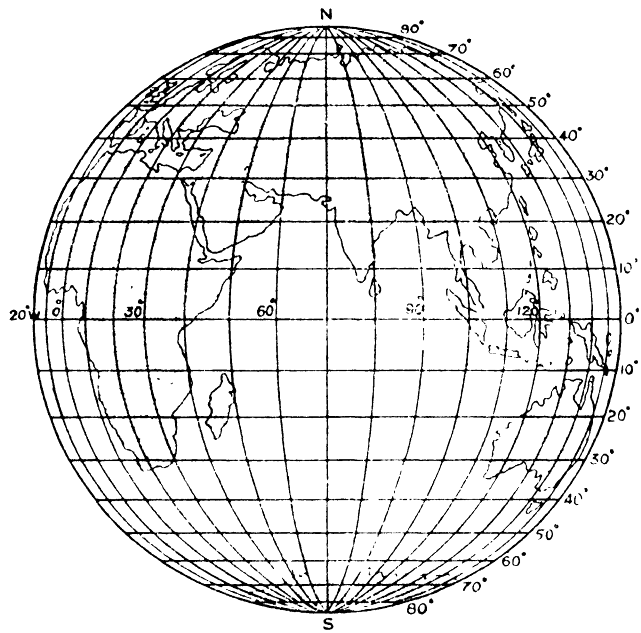


FIG. 47: ORTHOGRAPHIC PROJECTION.

The *Stereographic* projection gives a distorted view exactly opposite to that of the Orthographic, for the lines of latitude appear curved and farther apart as the Poles are approached, so that latitudes 80°N. and S. are almost semi-circular in shape. The distance between the meridians, also, increases outwards at the Equator, instead of decreasing as in the case of the Orthographic projection. This projection, therefore, is what is known as *Orthomorphic*, because there is an equal increase in scale along the parallels and along the meridians. It is also *Azimuthal*, as the correct direction of all lines drawn from the centre of the map is preserved.

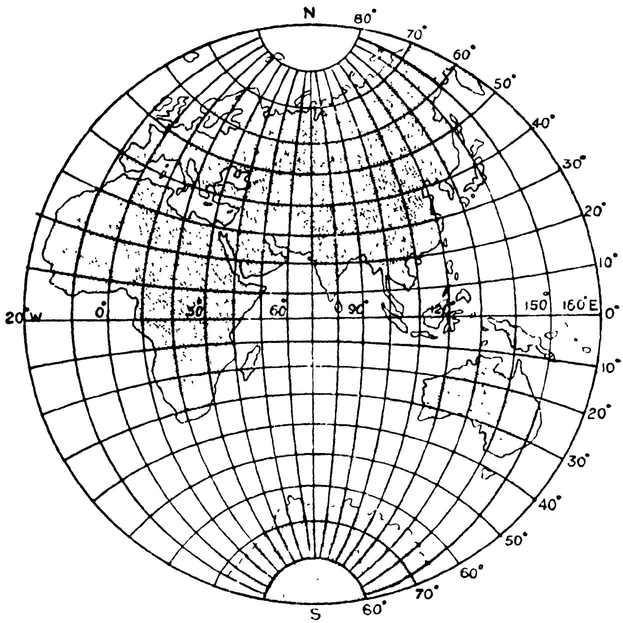


FIG. 48 : STEREOGRAPHIC PROJECTION.

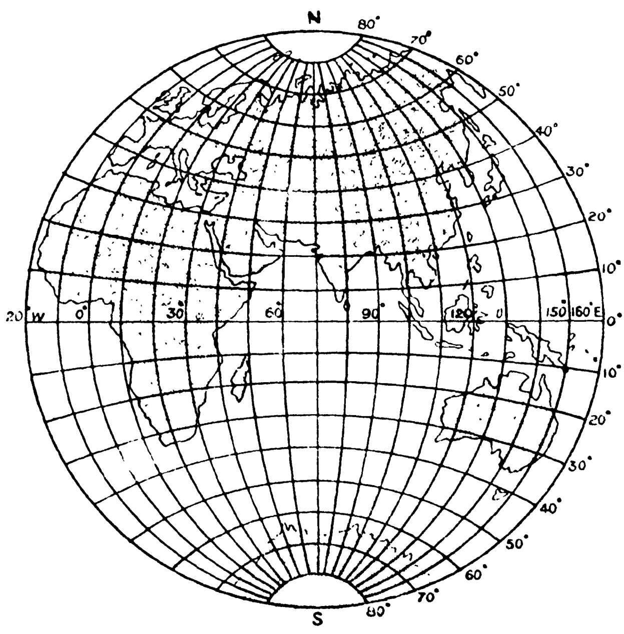


FIG. 49 : LAMBERT'S ZENITHAL OR AZIMUTHAL EQUIVALENT PROJECTION.

The ~~Zenithal projection~~ is an attempt to compromise between the opposite distortion effects of the Orthographic and Stereographic projections. In this projection (Fig. 49) there is expansion north and south, and compression east and west, similar to the Mollweide projection. It will be seen from the figure that the parallels are a compromise between those of the projections in Figs. 47 and 48, inasmuch as they are not only placed at points equidistant along the outer meridians but also pass through equidistant points on the central meridian. Moreover, the meridians in this projection cut the Equator at equal intervals, with the result that the Zenithal projection has the advantages of being an equal-area projection and of preserving the shape of the land masses fairly accurately, even on the margins.

It will, of course, be realised that hemispherical maps can be made with any part of the globe as the centre point. Maps of the Polar regions, with the North or South Pole as the centre point, are commonly formed on this projection, and more particularly on Lambert's Azimuthal Equivalent projection.

Simple Conical Projection with One Standard Parallel

Simple Conical projections are used for making maps of countries which extend through a limited number of degrees of longitude and which have a relatively small area. Maps of Europe, the British Isles, North America and Australia are therefore made by this method.

In this projection a cone of suitable size is imposed over a globe map in such a way that the cone touches the globe at the central parallel (known for this purpose as the "standard" parallel) of the area to be projected. This parallel, *e.g.*, 40° in Figure 50, is transposed on to the globe, and is then divided into the required number of equal parts,

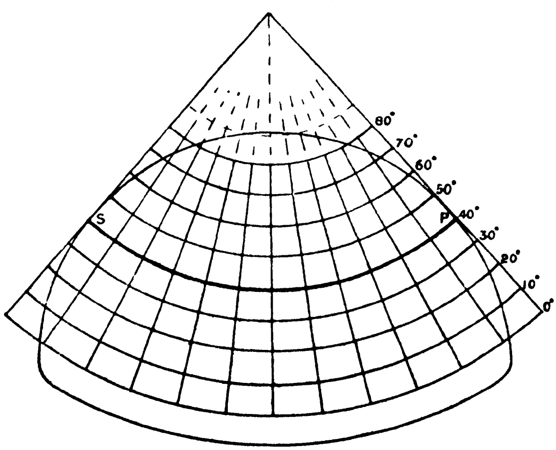


FIG. 50: SIMPLE CONICAL PROJECTION WITH ONE STANDARD PARALLEL.
(S.P. = Standard Parallel).

e.g., 12 parts in Fig. 50, through the dividing points of which meridians are drawn from the north point above the North Pole to the Equator. The remaining parallels are then drawn in at equal distances apart and parallel to the standard parallel.

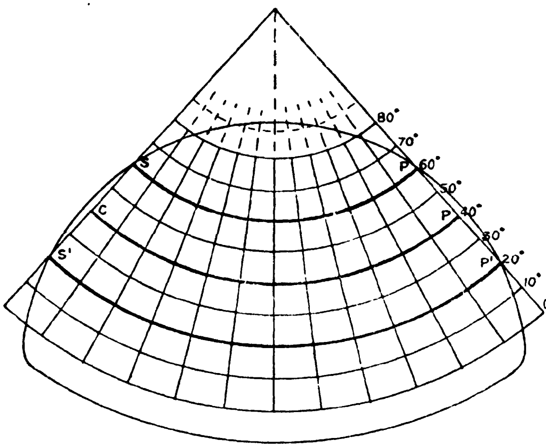


FIG. 51: SIMPLE CONICAL PROJECTION WITH TWO STANDARD PARALLELS.
(S.P. and S'P' = Standard Parallels; C.P. = Central Parallel).

It will be seen from Fig. 50 that the meridians in this projection take the form of straight lines converging on the apex of the cone above the Pole. The latitude lines, however, are necessarily curved, for by construction they are parallel to the standard parallel which, being an exact representation of the parallel on the globe, must be curved. This projection is a compromise between an equal-area projection and an orthomorphic projection, and, though distortion occurs both north and south of the standard parallel and increases as the distance from this parallel increases, for small areas it is only slight.

In applying this projection *any* parallel of latitude can be taken as the standard, provided it is the central parallel of the area to be projected.

Conical (Equidistant) Projection with Two Standard Parallels

This projection is an improvement on the Simple Conical projection. Instead of only one standard parallel, two are utilised by supposing that the projection is obtained by sinking the cone into the globe (see Fig. 51). The cone is imagined to cut the surface of the globe so that the central parallel of the area to be projected lies midway between the circles of intersection of the cone and the sphere, *e.g.*, if the central parallel of the area to be projected is 40°, the standard parallels may be 20° and 60°, or 30° and 50°, or any others similarly related.

This projection is therefore more accurate than the Simple Conical, for it has two parallels along which distances can be measured as

accurately as on the actual globe. The meridians, and the remaining parallels, are inserted in exactly the same way as in the case of the Simple Conical projection, except that the meridians can be marked off on two parallels instead of one, thus giving greater accuracy.

Like the Simple Conical projection, the Conical (Equidistant) projection (sometimes known as the *Simple Conical Projection with Two Standard Parallels*) is neither equal-area nor orthomorphic. It is, however, very suitable for making maps of small areas, *e.g.*, the British Isles, and is more suitable than the Simple Conical for larger areas, such as Europe, because the use of two standard parallels minimises the errors due to distortion to the north and south of the central parallel.

Bonne's Equal-area Projection

Bonne's projection is a modification of the conical projection. Any parallel of latitude may be taken as the standard parallel, and, as before, the surface of the cone is imagined as touching the globe along the standard parallel. The central meridian is drawn perpendicular to the centre of the standard parallel, and the remaining parallels appear as parts of concentric circles, centred at the Pole, and cutting the central meridian at equal distances. Each parallel is then divided into equal parts corresponding in total number with the number of meridians required and a meridian is drawn from the Pole to the Equator through each point so obtained. On this projection (see Fig. 52, which shows the Northern Hemisphere), all latitude and longitude lines, with the exception of the central meridian, appear as curves, and the meridians become closer together as the Pole is approached. Along each parallel the scales are correct as the parallels are drawn so as to be a representation of the equivalent parallels of a globe.

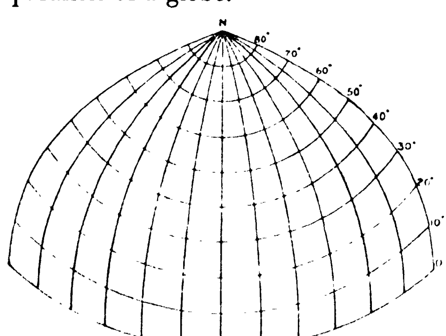


FIG. 52: BONNE'S EQUAL-AREA PROJECTION.

Bonne's projection is equal-area but not orthomorphic, and is suitable for maps of small countries which have a narrow longitude range and which are not situated near the Poles, as, for example, Palestine and other Near East countries.

QUESTIONS ON CHAPTER 5

1. Give some account of the characteristics, uses and limitations of Mercator's Projection. (*C.S., April,* 1931)
2. Point out the special merits and defects of any *two* of the following projections: Mercator's, Sanson-Flamsteed's, the Simple Conical with one standard parallel. State, with reasons, the purposes which the two selected are best fitted to serve. (*C.S., Oct.,* 1928)
3. Name one common projection suitable for a map showing world distribution of types of vegetation, and one suitable for a small-scale map of Europe. In each case give some account of the projection selected and explain why it is suitable for the particular purpose. (*C.S., April,* 1930)
4. Describe the properties of any map projection and discuss its merits. (*O. and C.J.B.,* 1928)
5. Give an account of the principles on which a Mercator's map of the world is constructed, and explain its special merits and defects. (*L.M.*)
6. Explain three of the chief modes of projecting maps of large areas of the earth's surface, and indicate the special advantages and disadvantages of each mode. (*L.M.*)
7. What are map projections and why are they necessary? For what purposes would you employ (*a*) a Mercator projection, (*b*) an equal area projection, (*c*) a polar zenithal equidistant projection? Give your reasons in each case. (*C.S., April,* 1934)
8. Contrast the appearance of the latitude and longitude network on *two* commonly employed map projections. State, with reasons, the extent of the earth's surface and kind of region for which each is particularly suitable. (*C.S., April,* 1937)

CHAPTER 6

MOVEMENTS OF THE OCEANS

WAVES

General Theory of Waves

WAVES are caused through the action of wind, which strikes the surface water and makes it rise and fall. Naturally, the stronger the wind the bigger the waves. Even in an exceptionally strong wind, however, the water is not affected below a depth of about 250 fathoms (1 fathom = 6 feet).

When we watch the waves in the open sea we get the impression that the water is moving forward in a procession of ridges, but if we watch closely a floating body in the path of the waves we will see that its motion has an *up-and-down* direction and that it has no *progressive* motion *horizontally*, *i.e.*, forward or backward. What does travel forward is the *distribution* of troughs and crests, while every particle of water remains almost vertically in line with its original position.

Actually, the particles of water forming a wave move in an elliptic course, having a to-and-fro motion or oscillation as well as an up-and-down motion. Yet they do not travel forward but tend to come to rest in a constant position. Near the shore, the elliptic movement cannot be completed, because the sea bottom checks the lower particles, which in turn checks those above them. The uppermost particles then roll off the crest of the wave and scatter themselves on the shore as surf. Moreover, the effect is to prevent the particles of water from resuming their true vertical position, and it is for this reason that it is dangerous to bathe in a heavy sea on a rapidly shelving beach, because what is known as the " undertow " or " backwash " tends to drag a swimmer down.

The denuding action of the waters of the ocean has already been discussed. (Chapter 3.)

OCEAN CURRENTS

Factors Giving Rise to Currents

In each of the oceans, there is a continuous circulation of water from one part of the ocean to another. These movements are called *currents*, and they are of the utmost importance owing to their effects on

navigation and in some cases on climate. Both the existence and the direction of these currents depend on a variety of factors, including the prevailing winds, differences in the density of the water, the rotation of the earth and the shape of the land masses.

WINDS.—The prevailing winds set up currents by blowing the surface water forward in front of them. If a map showing the permanent wind system of any ocean is compared with one showing the ocean currents, it will be seen that the flow of the waters conforms in its general direction to the circulation of the atmosphere.

DIFFERENCES OF DENSITY are due to differences in temperature and in salinity. The heated and, consequently, less dense water at the Equator moves along the surface of the oceans towards the Poles, whilst the cold dense water of higher latitudes creeps down as an undercurrent towards the Equator, where, on being warmed, it rises and again flows towards the Poles. This is sometimes called the *natural* movement of the oceans, because the differences in the density or nature of the waters is the initial cause which sets them in motion. The effect of density due to salinity is important in enclosed seas (see p. 114).

THE ROTATION OF THE EARTH deflects all moving bodies on the earth's surface towards the *right* of their course in the Northern Hemisphere and towards the *left* in the Southern Hemisphere. This tendency is known as *Ferrel's Law*, and a study of a map of the ocean currents of the world will at once show that they conform to this law. The waters in the oceans, instead of flowing directly north or south as the case may be, flow in a curving direction either left or right of what otherwise might be their true courses.

SHAPE OF THE LAND MASSES.—In many cases the original course of a current is obstructed by land. The land at the Equator, for example, prevents a complete circulation of water round the earth from east to west, and deflects currents northward and southward. Similarly, in the South Atlantic, the current flowing east from South America is deflected north by the land mass of Africa. There are many instances of such deflection due to the obstruction of land, as will be seen later.

The general direction of the flow of currents in all the oceans is shown in Fig. 53. It will be seen that the movement is *clockwise* in the Northern Hemisphere but *anti-clockwise* in the Southern Hemisphere, and this conforms to the general direction of the winds. Owing to the proximity of warm easterly currents, the west coasts of continents in the Northern Hemisphere enjoy a much warmer climate than the east coasts in corresponding latitudes, which are influenced by the cold currents from the north. In the Southern Hemisphere, there is a reverse effect; the west coasts of the continents have the cooler climate owing to the proximity of cool drifts.

The terms " warm " and " cold " used here and in Fig. 53 are, of course, relative terms only, *i.e.*, they are relative to the average

temperature of the latitudes concerned. Generally, there is only from 5 to 10 degrees difference between the temperature of the water in a current and that of the surrounding sea through which it flows.

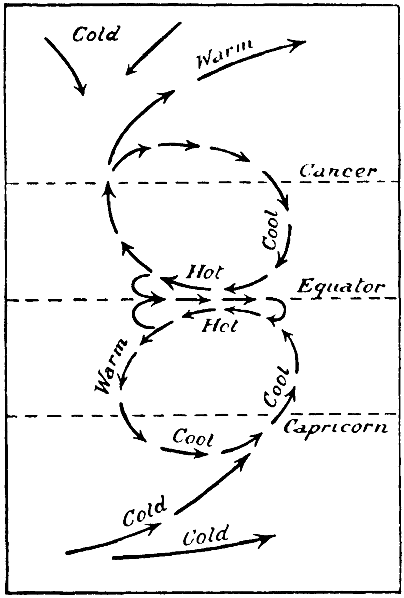


FIG. 53: THEORETICAL CIRCULATION OF OCEAN CURRENTS.

Currents, unlike winds, are named according to the direction *towards* which they flow.

Currents of the Atlantic Ocean

In the Atlantic Ocean, the Trade winds in the region of the Equator, combined with the other factors already mentioned, give rise to two main westerly currents—the *North Equatorial Current* between lats. 10°-20°N., and the *South Equatorial Current* between lats. 0°-10°S. The piling up of the waters of these two currents against the east coast of South America causes a minor easterly current, just north of the Equator, known as the *Guinea* or *Counter Equatorial Current.* On reaching the west coast of Africa, this current turns south and rejoins the South Equatorial Current.

The land mass of South America divides the South Equatorial Current into two parts, one of which flows south and the other north. The northern section joins the North Equatorial Current, and the united current them flows to the West Indies. where it divides. One part flows to the north of the islands as the *Bahamas Current* or *Antilles Current*

and the other part flows into the Caribbean Sea as the *Caribbean Current.* Between these two currents flows the *Cuba Counter Current.*

NORTH ATLANTIC CURRENTS.—The Caribbean Current, flowing through Florida Channel, rejoins the Antilles Current to the north of the West Indies, and from this point onwards the united currents flow eastward towards Europe as the famous *Gulf Stream*—the best known of all ocean currents.

The Gulf Stream has a speed of from 4–5 miles an hour and a surface temperature of 80°F. when it leaves the Strait of Florida. It continues along the coast of North America as far as Cape Hatteras and then, under the influence of the Anti-Trade or Westerly winds, passes out into the ocean, where its speed diminishes to little more than 1 mile per hour.

In mid-Atlantic the Gulf Stream loses its character as a well-defined current, but a drift of its warm surface waters continues to travel eastwards, under the influence of the winds, as the *North Atlantic Drift.* At about lat. 40°N., the Drift divides into a number of lesser currents. One current continues northward and the other turns eastward. The easterly branch divides off Spain, one part turning southward as the cool[1] *Rennel* or *Canaries Current* along north-west Africa, and the other flowing round the Bay of Biscay and west of the British Isles to rejoin the North Atlantic Drift south-west of Ireland. The northerly branch of the Drift divides off north-west Ireland, one branch—the warm *Irminger Current*—flowing towards Greenland, while the main Drift persists in its original direction past Scotland towards the west of Norway. The warming effect of the Drift has been felt even in the Arctic.

In the Western Atlantic, in the region of lat. 30°N., there is an area known as the *Sargasso Sea*, in which there is practically no movement. As a result, the surface of the ocean is covered by a vast accumulation of floating seaweed and débris, which forms a serious hindrance to navigation.

Flowing down the east coast of Greenland is a cold current known as the *East Greenland Current* or the *Arctic Current.* It is joined by the Irminger Current (which after turning southwards is, of course, a *cool* current), and then flows round the south of Greenland and divides into two parts, one of which flows north as a *warm* current up the west coast of Greenland, while the other turns south as a *cool* current and joins the *Labrador Current.*

The Labrador Current—the most important cold current of the North Atlantic—flows southward from the polar regions through Baffin Bay and Davis Strait, wherefrom it derives its other name of the *Davis Strait Current.*

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[1] It is necessarily a cool current to all places nearer the Equator than the point from which it flows.

South of Newfoundland this current divides into two branches. The smaller part passes through Cabot Strait into the St. Lawrence as the *Cabot Current*, and through Belle Isle Strait as the *Strait Current*, which then rejoins the main current. The major part flows

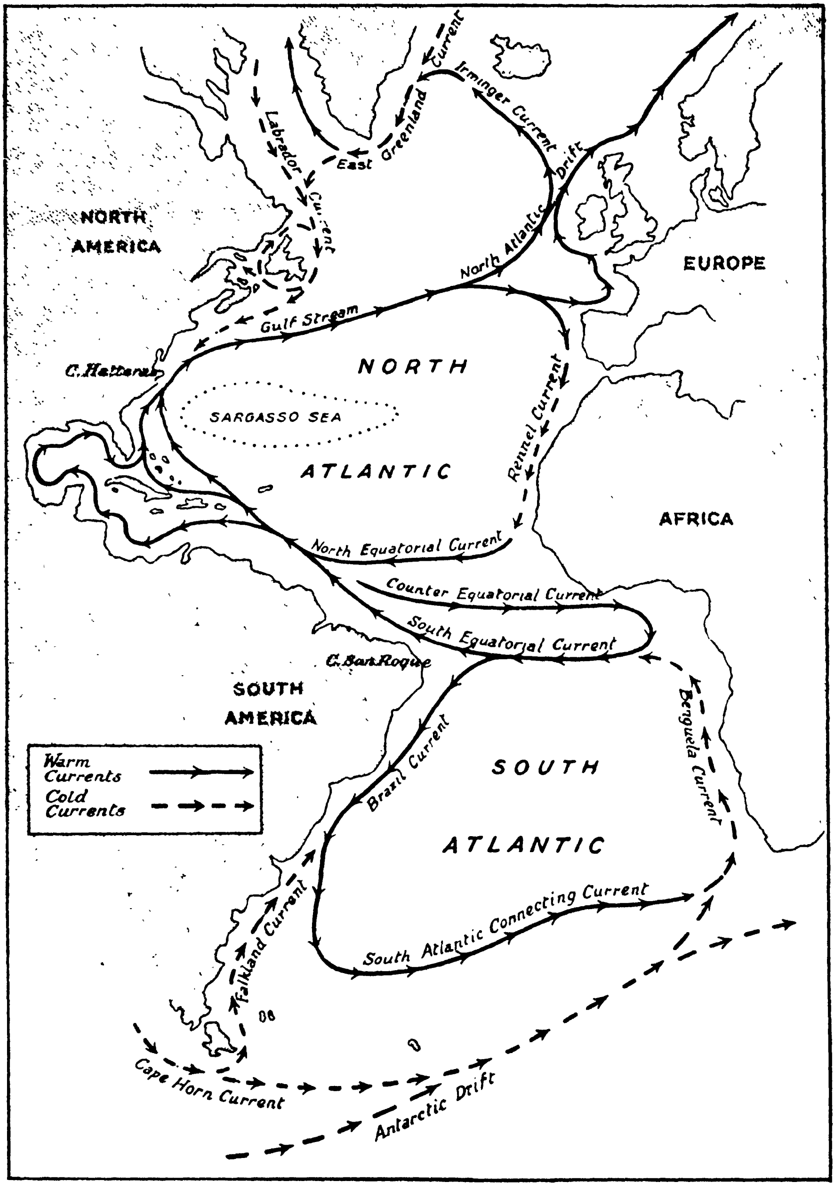

FIG. 54: CURRENTS OF THE ATLANTIC OCEAN.

south-westwards along the coastline of North America, passing between the coast and the Gulf Stream, until, in the vicinity of Cape Hatteras, the relative density of its cool waters causes it to sink below the surface.

The Labrador Current carries along with it great volumes of Arctic water and great masses of ice, and the meeting of its cold waters with the warm waters of the Gulf Stream causes the fogs which are so prevalent and dangerous to shipping in the Gulf of St. Lawrence and off the coast of Newfoundland.

South Atlantic Currents.—The current system of the South Atlantic bears a strong resemblance to that of the North Atlantic. As has been stated, part of the South Equatorial Current flows south off Cape San Roque, along the coast of Brazil where it takes its name of the *Brazil Current*—a *warm* current because it flows from equatorial to cooler regions. After following the coast to about lat. 40°S., it moves eastwards into the Atlantic as the *South Atlantic Connecting Current*, and turns gradually in the direction of the African coast along the northern limit of icebergs from the Antarctic region.

The land mass of Africa deflects this current up the west coast of that continent as the cold *Benguela Current*, which rejoins the South Equatorial Current just south of the Equator. The coldness of the Benguela current is reinforced by an upwelling of deep ocean water, caused by a powerful off-shore wind blowing a drift of surface water away from the African coast. This circular system of currents in the South Atlantic leaves a central area which, like the Sargasso Sea, is practically free from movement.

The cold current entering from the Pacific round Cape Horn, known as the *Cape Horn Current*, sends a branch—the cold *Falkland Current*—for some distance northwards up the Patagonian coast, but the main part of the Cape Horn Current continues eastward as part of the cold *West Wind Drift* or *Antarctic Drift*.

The cold currents which come from Polar regions, such as the Labrador and Falkland Currents, are composed largely of water formed by the melting of ice, and consequently are of a lower salinity than the Atlantic water. When, therefore, these currents come into contact with the more saline waters, they remain on the surface owing to their lower specific gravity, but as they proceed towards the Equator they encounter warmer, and less dense, waters and so sink below the surface.

Currents of the Indian Ocean

The relation between winds and ocean currents is nowhere so marked as in the Indian Ocean. In this region the winds are definitely seasonal, and as their direction changes so also does that of the currents. We must, therefore, consider the currents of the Indian Ocean in two

seasons, *viz.*, January and July. (See Figs. 55*a* and 55*b*, to which reference should constantly be made as the following paragraphs are read.)

JANUARY CURRENTS.—At this period, a westerly current flows from the Straits of Malacca, round the Bay of Bengal, past Ceylon, and round the Arabian Sea, keeping close in-shore all the way, except just off the Gulf of Oman. This current is largely influenced by the North-East Monsoon, from which it takes its name, the *North-East Monsoon Drift.* After continuing down the east African coast as far as Zanzibar, it turns eastward, just south of the Equator, and becomes known as the *Indian Counter Current.* This latter part is weak and irregular in its action.

The system just described should be compared with the North and Counter Equatorial Currents of the Atlantic Ocean. The North-East Trade winds largely influence the North Equatorial Current just as the North-East Monsoon influences the North-East Monsoon Drift. The counter-current in each ocean is a kind of backwash in a belt of calms.

The South Equatorial Current of the Atlantic has its counterpart in the strong *Equatorial Current* of the Indian Ocean. They are both set in motion by the South-East Trade winds and therefore they both

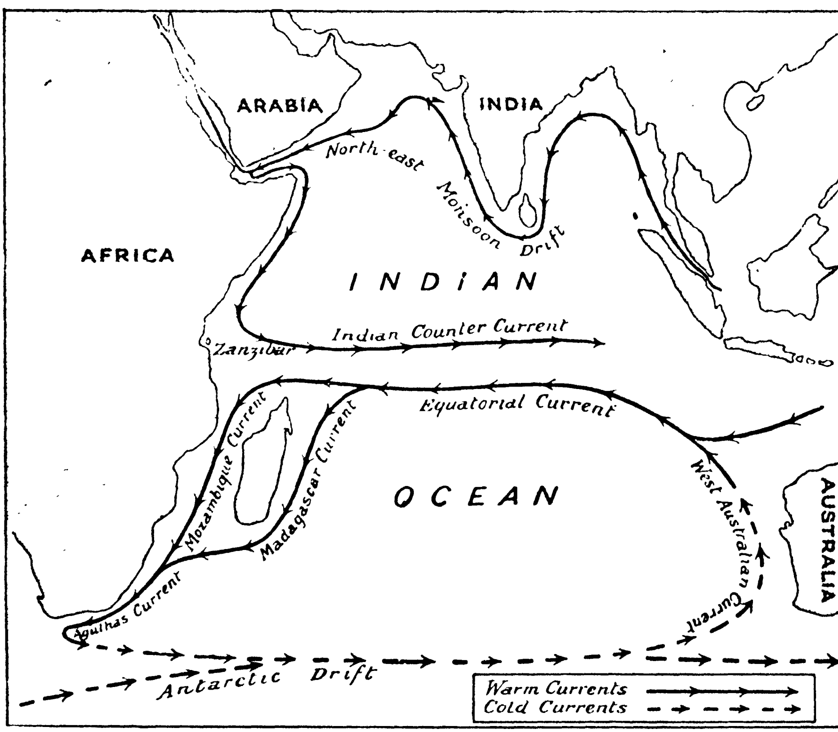

FIG. 55*a*: CURRENTS OF THE INDIAN OCEAN—JANUARY.

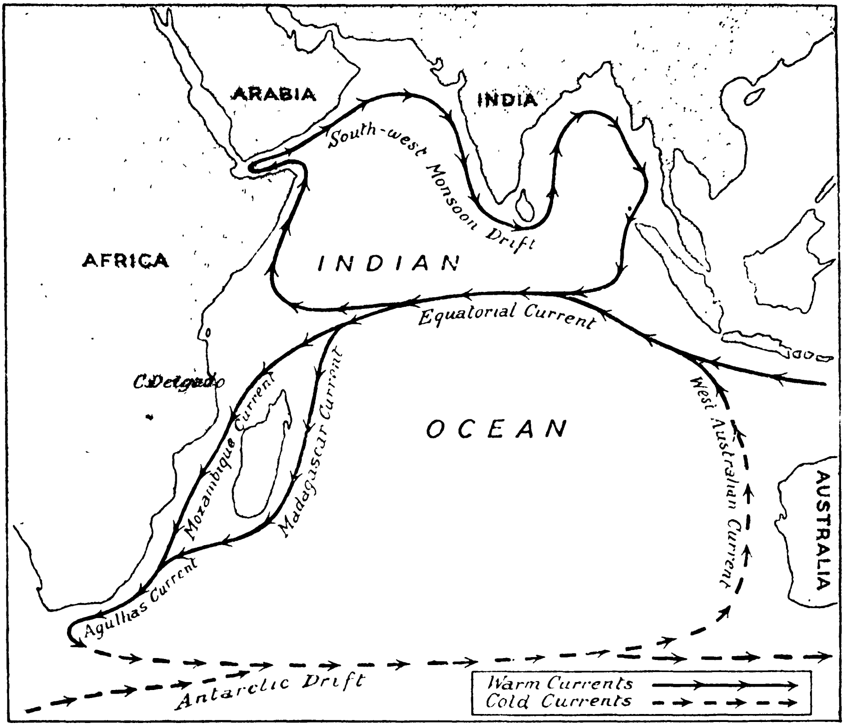

FIG. 55b: CURRENTS OF THE INDIAN OCEAN—JULY.

flow westward. The Equatorial Current of the Indian Ocean is deflected on reaching the east coast of Africa, part flowing through the Mozambique Channel as the warm *Mozambique Current*, and part past the eastern coast of Madagascar as the warm *Madagascar Current*. The divided current reunites at about lat. 30°S. to form the *Agulhas Current*, which, on coming into the region of the Westerly winds south of the Cape of Good Hope, is turned eastwards and carried as a cold current to the west coast of Australia. Here part of the current is deflected up the west coast of the continent as the cold *West Australian Current*, which flows into the Equatorial Current and becomes gradually warmer as it travels Equatorwards.

JULY CURRENTS.—At this period the system of currents in the northern part of the Indian Ocean is the reverse of the system prevailing in January. The South-West Monsoon takes the place of the North-East Monsoon, and the westward flowing current is replaced by one flowing *east*. This current, known as the *South-West Monsoon Drift*, flows in the opposite direction to the January current and along the same course, but it does not enter the Straits of Malacca. As there is no belt of calms at this season, the Indian Counter Current disappears, and after flowing

for some distance south-westward, the Monsoon Drift merges with the Equatorial Current.

The direction of the currents in the southern section of the Indian Ocean in July is almost the same as that prevailing in January. The only difference is that the Equatorial Current is pulled slightly northward, and takes the place of the Indian Counter Current. In the vicinity of Cape Delgado on the African coast, part of this water comes under the influence of the South-West Monsoon and is deflected northwards, to merge with the South-West Monsoon drift and so complete the northern circulation.

Currents of the Pacific Ocean

The currents of the Pacific Ocean are in many ways similar to those of the Atlantic Ocean, the main differences being due to the difference in the forms of the enclosing land masses.

THE NORTH PACIFIC CURRENTS.—The North Pacific has a *North Equatorial Current* flowing westwards towards the Philippines. Here it is turned northwards and later is deflected north-eastward by the Japanese Islands, flowing east of them as the warm *Kuro Siwo* or *Black Stream*, so called because of the dark colour of its waters. It soon comes under the influence of the Westerlies, and, changing its course to due east, it becomes the *West Wind Drift.* When it reaches the coast of British Columbia, the current sends a small branch northwards along the coast of northern Canada and Alaska to circle back into the main drift. The greater part, however, turns southward along the west coast of America as the cool *California Current*, which, south of Cape San Lucas, turns westward into the North Equatorial Current.

THE SOUTH PACIFIC CURRENTS.—In the South Pacific the general circulation is similar to that of the north Pacific Ocean, but there is considerable modification owing to the presence of numerous islands. The *South Equatorial Current*, like the similarly named current of the South Atlantic, flows westward, and after sending off many branches between the various islands, reaches the east coast of Australia. Here the main stream turns south as the *East Australian Current*, which, after being divided by the islands of New Zealand, reunites and is then forced eastwards by the Westerly winds of the lower latitudes. The current turns north on reaching the west coast of South America, and finally flows into the main stream as the cold *Peruvian Current* (see below). The counter current of the Atlantic has its counterpart in the Equatorial Counter Current of the Pacific, which flows almost due eastward between the two westerly main streams.

COLD PACIFIC CURRENTS.—Owing to the narrowness of the passage from the North Pacific to the Arctic Ocean, the current system is much simpler than that which is found in the corresponding part of the

Atlantic. The Kuro Siwo does not divide into many branches as does the Gulf Stream, but the Labrador Current has its counterpart in the cold *Oya Siwo*, or *Kurile Current*, which flows south from Behring Strait between the Kuro Siwo and the eastern Asiatic islands. Its meeting with the Kuro Siwo, like that of the Labrador Current with the Gulf Stream off Newfoundland, gives rise to fogs off the east coast of Japan.

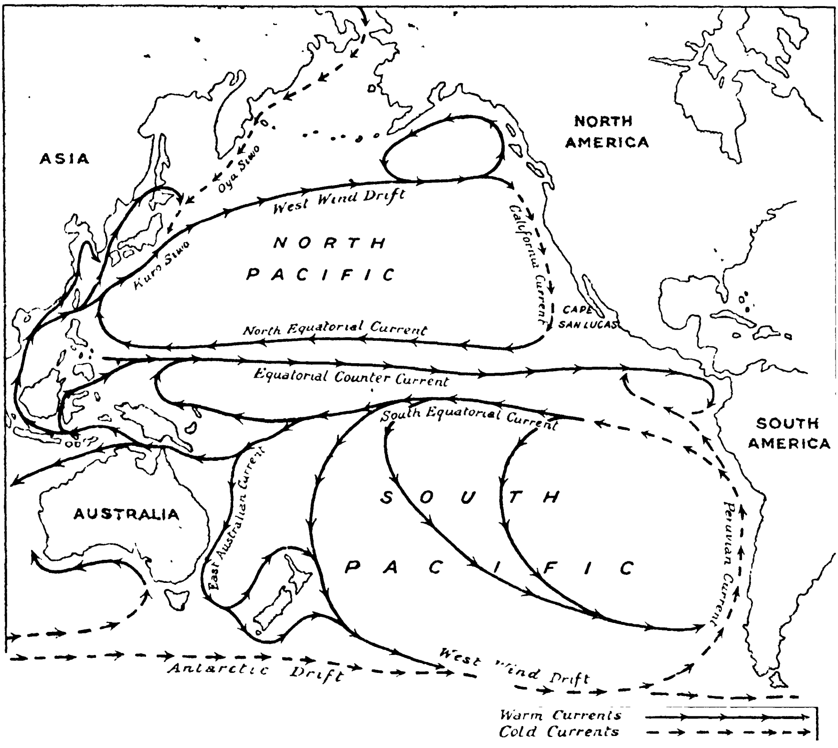

FIG. 56: CURRENTS OF THE PACIFIC OCEAN.

Similarly, the Falkland Current of the Atlantic finds its duplicate in the current which flows north-east between Australia and New Zealand, but, as Australia is not in such low latitudes as Patagonia, the current is not so definitely in the track of the Westerly winds and is therefore not so strong as the Falkland Current. In the extreme south the cold *Antarctic Drift*, mingling with the West Wind Drift, sends a cold branch up the coast of South America as the *Peruvian* or *Humboldt Current*. As is the case off the west coast of Africa, the upwelling of cold water off the Peruvian and Chilean coasts accentuates the coldness of the Peruvian current.

Currents of Enclosed Seas

In enclosed seas, such as the Mediterranean and the Baltic, the circulation of the water is determined by the relation between the density of the water in the enclosed sea and that of the water in the adjacent ocean. The density of the enclosed water is increased by evaporation (which increases the salinity), but is decreased by the inflow of fresh water from rivers and rain, and the circulation of the waters is ultimately determined by which ever of these two influences predominates. Evaporation, for example, will tend to lessen the quantity of water, lower its level and increase its density. If this density is increased relative to that of the neighbouring ocean, a surface current of comparatively fresh water will flow in from the ocean to preserve the general level, and an undercurrent of dense salt water will flow outwards into the ocean.

If, on the other hand, the inflow of fresh water from rivers and rains causes a decrease in density and an increase in the quantity of water, a fresh surface current will flow from the enclosed sea into the ocean and a denser salt water under-current will flow in from the ocean.

As a result of the operation of such forces, therefore, the water in an enclosed sea is always kept at the same level as the ocean with which it is connected. In the Mediterranean and Red Seas, for example, where the strongest influence is evaporation, strong surface currents flow in, and dense salt water currents flow out at a lower level. In the Black Sea, the Baltic Sea and Hudson Bay, where there is an abundant supply of fresh water from the rivers, the surface currents flow outwards and the underwater salt currents flow inwards. Hence, these expanses of water freeze in winter, whereas the Mediterranean, which is more salty, is never frozen. The vast volume of water brought down to the sea by great rivers such as the Amazon and the Congo cause currents which extend to a considerable distance from their mouths.

TIDES

The Theory of the Tides

The tides are formed by the alternate rising and falling of the water in oceans and seas, the rising being called the *flood* tide and the falling the *ebb* tide. The hydrosphere is kept in position by the force of gravity, in the same way as are all moveable objects on the earth. But other influences, such as the moon, the sun and centrifugal force, have an attractive force which is constantly exerting a "pull" on the earth and its surrounding waters. This pull causes slight differences in the force of gravity in different parts of the earth, and, while it has no appreciable effect on the solid globe, it is sufficient to deform the more easily modified water envelope. In brief, the attractive forces partly counteract the gravitational pull of the earth on its waters, with the result that the water is heaped up on opposite sides of the earth to form the tides.

The attractive power of the moon on the earth is very much greater than that of the sun owing to its much greater nearness, and actually the effect of the sun is not to cause independent tides, but merely to increase or diminish the height of the tides caused by the moon, *i.e.*, the *lunar* tides, according as it is pulling in the same or in a different direction.

Centrifugal force is developed because the earth, in addition to rotating on its axis, describes a circle every lunar month, during which all parts of the earth also describe circles of the same size and in the same direction[1]. Hence, the centrifugal force is of the same amount and in the same direction in all parts of the earth. Now at the centre of the earth, the direction of the centrifugal force is away from the moon and as this force is in the same direction in all parts of the earth it is everywhere directed away from the moon. The attractive force of the moon, however, is not the same at all points on the earth, but is greatest on the part that faces the moon. Thus, on the side nearest the moon the attractive force of the moon is greater than the centrifugal force; in the centre of the earth the two forces are equal; and on the side of the earth farthest away from the moon the centrifugal force is greater than the attractive force of the moon. On the side of the earth facing the moon the waters are therefore pulled towards the moon because the attractive force of the moon is greater than the centrifugal force, whilst on the opposite side they are pulled away from the moon by the excess of centrifugal force over the moon's attractive force (Fig. 57).

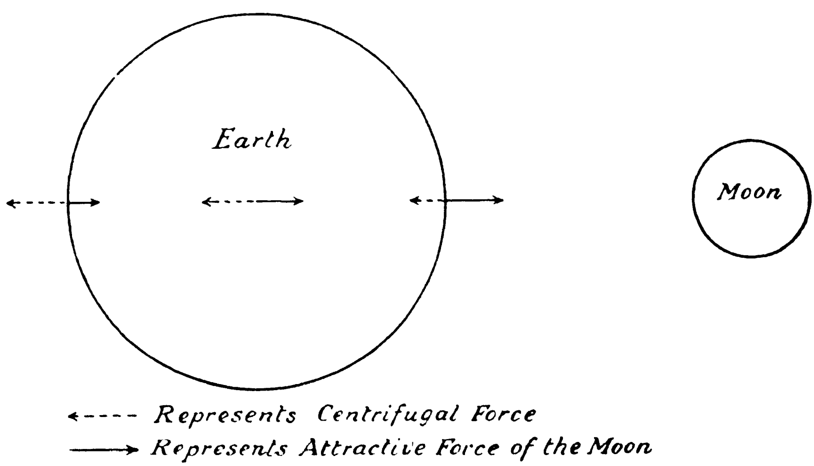

FIG. 57: ATTRACTIVE FORCE AND CENTRIFUGAL FORCE.

[1] This statement is made without proof, but any book on Dynamics will make clear the theory on which it is based. For a fuller treatment of the particular case Chapter X of *Physical Geography*, by P. Lake, or Chapter XXV of *Admiralty Manual of Navigation* may be consulted.

The theory of the cause of tides is not easy to understand, but a study of Fig. 57A may be of assistance. When the moon (M) is opposite point *A* on the surface of the earth (E), the excess of its attractive force over centrifugal force pulls the waters outwards to be heaped up at *A* ; and since at *B*, on the side of the earth opposite to *A*, centrifugal force is greater than the attractive force of the moon, the waters are at the same time pulled outwards to be heaped up at *B*. This gives high tides at *A* and *B*, and since the water must be drawn from other parts of the earth, there will be low tides at *C* and *D*. This is the position also when the moon is opposite *B*, except that then the heaping up of water at *B* is caused by the excess of the attractive force of the moon over centrifugal force and at *A* by the excess of centrifugal force over the attractive force.

When the moon is opposite *C* or *D* there will, for similar reasons, be high tides at *C* and *D* and low tides at *A* and *B*, for then the waters will in each case be heaped up at *C* and *D*.

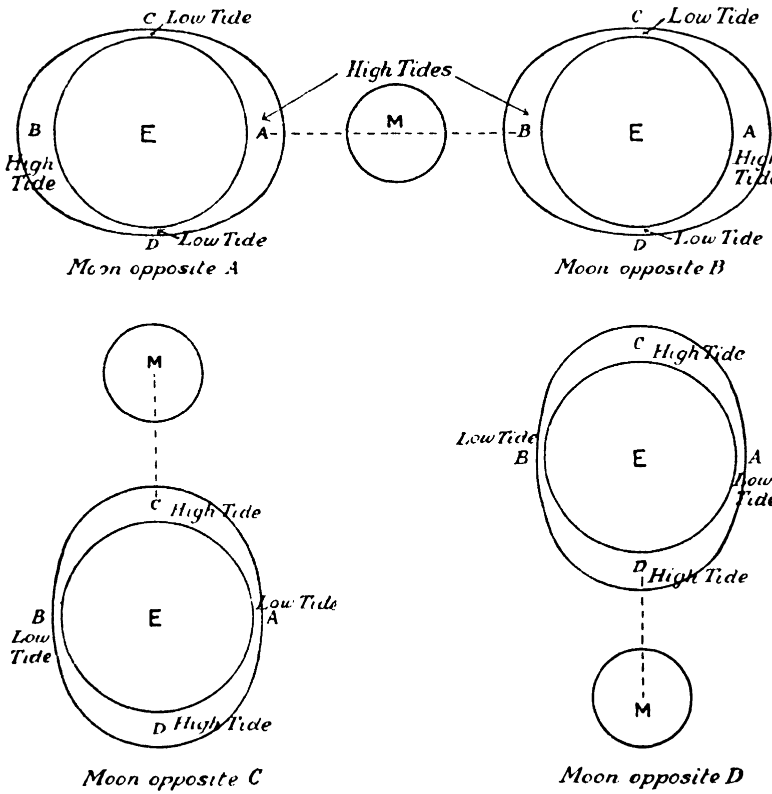

FIG. 57A : TIDES.

The revolution of the moon round the earth causes every meridian to come under the maximum influence of the moon once every *lunar* day, so that each place on the earth's surface has two high tides and two low tides daily. As, however, the moon travels along its orbit in the same direction as the rotation of the earth, it takes longer than a solar day for each meridian to move from its position opposite the moon and to return to that position. The lunar day is longer than the mean solar day by 52 minutes. High tides thus follow one another at any particular place on the earth's surface at intervals of 12 hours 26 minutes, and not at intervals of 12 hours. The same is true, of course, of low tides.

Spring and Neap Tides

As has been said, there are no independent *solar* tides, *i.e.*, tides due to the influence of the sun, but at certain times the forces due to the attraction of the sun and the earth's motion round it (centrifugal force) reinforce or counteract the similar forces between the earth and the moon which we have already described. At full moon and new moon, the sun, earth and moon are to all intents and purposes in a straight line, and, as a result, unusually high tides known as *spring* tides occur (Fig. 58). When the moon is in its first and third quarter, however, the sun and moon are at right angles to one another in relation to the earth. At this period, therefore, the forces partly neutralise one another and unusually low tides, called *neap* ("nipped") tides occur (Fig. 58).

The highest spring tides and the lowest neap tides do not coincide *exactly* with the relative phases of the moon, but occur from two to three days later, for the attractive forces at their highest do not cause the waters to gain their greatest momentum immediately. At London Bridge, for example, the spring tide is at its highest and the neap tide at its lowest 2½ days after the relative phases of the moon.

Tidal Waves and Bores

In the open ocean there is nothing to interfere with the movements of the water, and the difference between high tide and low tide is but a few feet. When the tidal wave enters a shallow sea, however, the front of the wave is retarded, the waters are piled up, and the height of the wave increases. Owing to the shallowness of the British seas, for example, the difference between high and low tide is considerable, amounting in many parts to as much as 30 feet or more.

Where a tidal wave enters a channel or gulf which becomes narrower as well as shallower, the tidal effect is even more marked. The wave is piled high as the channel constricts and as the leading water is retarded. Thus, at Bristol the difference between high and low water during the

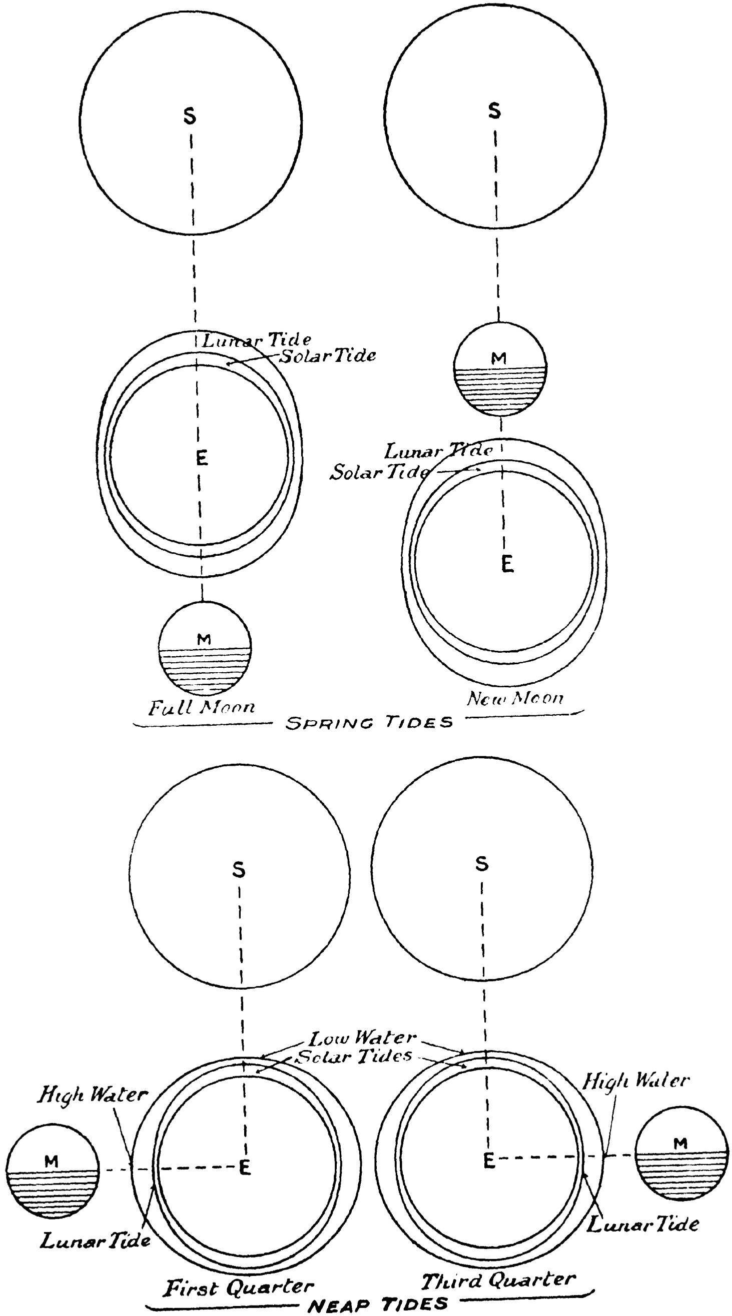

FIG. 58 : SPRING AND NEAP TIDES.

spring tides is 42 feet. In Canada, the difference between the high and low tides of the Bay of Fundy is even greater, being as much as 70 feet.

Where a tidal wave ascends the mouth of a river which contracts like a funnel, it progresses as a nearly upright wall of water, and is known as a *bore* or *eger*. These phenomena are to be found in the Severn and the Trent in England, in the Amazon in South America, and in the Yangtse-Kiang in China. They are not usual, however, and the rise of the tide in most river estuaries is almost imperceptible. Moreover, whilst tides entering narrow openings are especially marked owing to the confinement of the water within narrow limits, the effect of the tide is small if, after passing the narrow part, the sea opens out again, for then the influx of water is rapidly spread over a wide area. It is for this rèason that the Mediterranean Sea is practically tideless.

Where a tidal current rushes through a group of islands or a narrow strait or channel, a very rapid, strong and dangerous current or eddy may be set up. These rapid currents are known as tidal " races " or " whirlpools ".

The high tides, with the currents they set up, are of immense benefit to the British Isles. Twice a day they provide deep water in the ports and estuaries, and in many cases enable vessels to proceed far inland from the sea. Also, they keep the harbours and river mouths free from accumulations of rock waste and, by their strong action, keep clear the straits and channels round the coasts.

QUESTIONS ON CHAPTER 6

1. Draw a sketch-map to show the chief surface currents of the Atlantic Ocean, and give a concise account of the Gulf Stream. (*C.S.C.*, 1928)
2. What do you know of ocean currents? (*C.I.I. Associateship, Marine Branch*, 1931)
3. Give an account of the causes of ocean currents. Draw a sketch-map showing the courses of the main currents of the Pacific Ocean. (*L.M.*)
4. Give a diagram of the surface circulation of the Atlantic. State the causes of the currents and their effects on climate. (*L.M.*)
5. How are tides caused? Describe the tidal phenomena off the east coast of England and in the Irish Sea. (*L.M.*)
6. What change would be observed in the hour on the height of the high tide if the observations were continued at a place for one month? State briefly the cause of each difference that would be noticed. (*N.U.*)
7. Describe those movements of the water in oceans and seas known as (*a*) tides, (*b*) ocean currents. Do not explain the causes of the movements. (*C.S., April*, 1938)
8. To what extent are the great wind systems responsible for the chief ocean currents? Illustrate from the North Atlantic and Indian Oceans. (*L.M.*)

CHAPTER 7

THE ATMOSPHERE

THE envelope of air which completely surrounds the globe on which we live is called the *atmosphere*. As air is essential to life, its chemical composition is of great importance, but the importance of the different constituents is not proportional to their relative bulk in the atmosphere.

Constituents of Pure Air

Nitrogen, about	78 per cent.	Inert gases, about	·94 per cent.
Oxygen, ,,	21 ,,	Carbon dioxide, about	·06 per cent.

Even the trace of carbon dioxide, for example, is indispensable as it is necessary to the existence of all green plants. These alone amongst all forms of life have a special food-making function. The greenness of their leaves and stems is due to the presence of a substance known as *chlorophyll*, which brings about the chemical combination of water with the carbon dioxide of the atmosphere under the influence of sunlight. In the process, oxygen is released into the atmosphere, whilst the resulting simple sugar compound is elaborated by the subtle chemistry of the plant into the various starches, proteins and fats which it needs.

All other living things—man, bird and beast—support themselves on the foods thus built up by green plants primarily from the carbon dioxide of the air. But all living things, in doing this, break down these foods into their elementary constituents again ; and in this process oxygen is absorbed whilst carbon dioxide is released.

Life on the earth is therefore a continual process involving two opposite chemical actions : one a building-up—called *photosynthesis*—carried out by green plants only and affecting the atmosphere as an exchange of oxygen for carbon dioxide ; the other a breaking-down—characterised by *respiration*—carried out by all living things, including green plants, and affecting the atmosphere as an exchange of carbon dioxide for oxygen. But whereas photosynthesis requires sunlight and so occurs only during daylight, respiration goes on continually.

The nitrogen in the air plays no directly active part in maintaining life, and its function is mainly to dilute atmospheric oxygen to the proper concentration. If the proportion of oxygen in the atmosphere were much different from what it is, life as we know it could not exist. A stronger concentration would cause living tissues to burn away faster than they could be renewed, while a lower proportion would prevent the breaking down of foods at a sufficiently rapid rate to maintain the supply of energy for the life processes.

As we shall see later, an important feature of the atmosphere is its power to hold in suspension both dust and water-vapour.

Atmospheric Pressure

The air, like every other substance, has weight and is held around the earth by the force of gravitation. Both land and water surfaces are consequently subject to a pressure resulting from the weight of the atmosphere, which extends upwards for about 200 miles. Moreover, the lower layers of the atmosphere are compressed by the weight of the layers above them. Hence, as we ascend in a balloon or up a mountain, we find that the pressure of the air, *i.e.*, the weight of the air above us, gets less and less. At the same time the air itself gets less and less dense or compressed, until a point is reached where it is too rare to support life.

The weight of the atmosphere produces at sea-level a pressure of about 15 pounds on a surface of one square inch. This *atmospheric pressure*, as it is called, varies not only from place to place but also from time to time, and if we wish to measure it at any time and place we must use a special instrument for the purpose, known as a *barometer.*

In its simplest form this is a U-shaped tube, one end of which is sealed and the other left open. Mercury is poured into the open end until the sealed arm is filled, and the tube is then fixed in a vertical position. When this is done, the mercury falls in the sealed arm and leaves a vacuum between its surface and the sealed end of the tube. As the mercury falls in the closed arm, it rises to the same extent in the open arm ; and, when this movement ceases, it is evident that a balance must have been reached between the pressures on the lowest part of the mercury. These pressures are : on the *sealed* side, the weight of the column of mercury alone ; on the *open* side, the weight of a *shorter* column of mercury *plus the pressure of the air on its upper surface.* It is evident that the shorter column of mercury in the open end of the tube balances a column of the same height in the sealed end; and therefore the *excess* of mercury in the sealed end must be balanced by the air pressure in the open end. Hence, if we measure the difference in the heights of the two mercury columns we get an expression for the atmospheric pressure in terms of inches of mercury. When, for example, we say that the atmospheric pressure at place *A* is 29 inches, we mean that the pressure of the air at *A* is such that it will balance a 29-inch column of mercury ; and the height of the column will be the same whatever its thickness. Normal atmospheric pressure is calculated to be 29·53 inches. For the purposes of measurement the tube is marked with a scale of inches (or centimetres).

The barometric reading must be corrected for variations in temperature, for mercury expands under the influence of heat, and the weight per square inch of a column of a given height will therefore vary with its temperature. Again, as atmospheric pressure varies with height above sea-level, barometric readings must be corrected in this regard also before they are of any use for accurate comparative purposes. The method is, therefore, to adjust the actual reading at any place to

what it would be if the place were at sea-level, by *adding* one inch of pressure to the reading for every 1,000 feet of height above sea-level. Thus, if a place is 5,000 feet above sea-level, five inches must be added to the actual barometric reading to reduce it to an equivalent reading at sea-level.

Although, as has been previously stated, the atmosphere extends upwards for at least 200 miles, half of its mass is concentrated in the bottom 3 miles. This can be proved by taking barometric readings at the top of, say, Mt. Blanc (15,000 ft.). There the mercury would be found to stand at only 15 inches, *i.e.*, at half the normal height, so proving clearly that half the mass of the atmosphere is below the barometer.

TEMPERATURE

Insolation

The source of heat is the sun and the incidence of the sun's rays on the earth's surface is usually termed *insolation*.

The sun's radiant energy comprises rays or constituents of very variable quality and power. One constituent known as the X-ray is used up in heating the air, but it is a negligible proportion of the whole. The bulk of the sun's radiant energy passes through the air without warming it at all.

But although air is scarcely affected by the passage through it of solar rays (sunshine), this is not the case with any solid or liquid matter in the atmosphere—such as dust and water vapour—for these readily absorb the solar rays and are heated thereby. Any other solid object in the air or on the earth's surface—the human body for instance—is readily heated by sunshine, as we know quite well. Incidentally, it may be said that it is a very fortunate thing that the quantity of dust and water-vapour in the air is so great ; were it not so every living plant on the earth would be burnt up.

When the solar rays reach the earth's surface they are almost entirely absorbed by the soil, rocks, water and vegetation—dark soils absorbing the heat more readily than the light soils. The heated soils and water radiate the heat out again into the air, but it is now in a new form—known as dark heat rays—which the air *can* absorb. In this way, the air close to the ground is heated by radiation. As this heated air rises to higher levels it *conveys* the heat with it and loses part of that heat to the upper layers of air, which thus become heated by *convection*.

The speed of this radiation from the ground to the air is very important. If it proceeds very rapidly, heat is quickly transferred from ground level to higher levels and a severe frost may ensue before the sun is up again. As it is in the lower levels—the bottom 30 feet or so—that the majority of men and plants live, the speed of radiation is obviously a matter which concerns us all very much.

Now it is found that solids and water vapour not only absorb the sun's radiant heat in its downward passage through the atmosphere but that they also absorb the dark heat rays radiated from the earth. Hence these constituents if present in the atmosphere in large quantity tend to keep the lower atmosphere warm by confining to it the heat radiated from the earth—thus benefiting all living things.

It is for these reasons that, in moist climates like that of Britain, the days and nights are seldom very cold and we owe it to the dust and the clouds—and to the carbon dioxide, too—for equalising for us our daily temperatures ; for preventing the sun from burning us up and the nights from becoming too cold.

It must be noted that all recorded temperatures are *shade* temperatures—the temperatures, that is to say, of the air—as the thermometer is always shaded from the sun's rays.

Places within the Tropics receive the sun's rays more directly than places nearer the Poles. A given area near the Equator, therefore, not only receives more light than a similar area near the Poles where the rays strike obliquely, but is also more intensely heated. This is illustrated in Fig. 59, wherein it will be observed that a given number of parallel rays of the sun distribute themselves over a smaller area at the Equator than the same number do over the regions mid-way between the Equator and the Poles. Apart from this, the sun's rays which reach the Tropics have less atmosphere to pass through before they strike the earth so that a greater proportion reach the earth and less heat is lost by atmospheric absorption. Tropical regions thus experience a higher mean temperature than any other parts of the world.

Besides the degree of intensity of the solar radiation, the length of time during which the sun is shining in any particular region is of

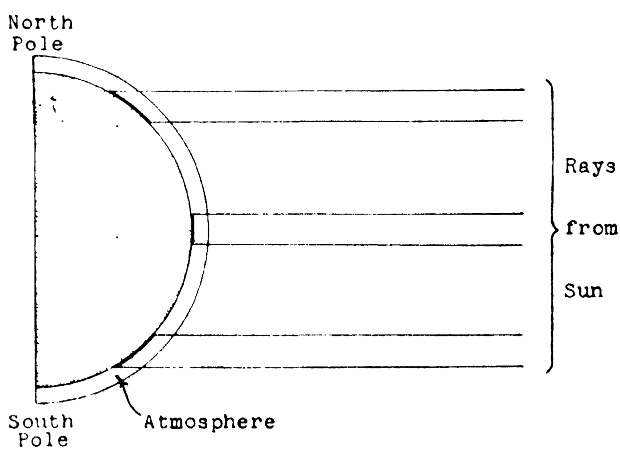

FIG. 59 : LATITUDE AND INSOLATION.

importance. We have seen in an earlier Chapter that, owing to the inclination of the earth's axis, the period at which the sun is above the horizon varies for different places at different times of the year, except at the Equator, where the sun is above the horizon for roughly twelve hours a day throughout the year. From the Equator towards the Poles (*i.e.*, as the higher latitudes are reached) the summer day gradually becomes longer and the winter day shorter. The falling-off in intensity of the insolation in the higher latitudes is, therefore, to some extent counter-balanced in summer by the greater continuous length of time during which the sun is shining, but is accentuated in winter by the short length of time during which the sun is above the horizon. Thus, the *range* of temperature experienced during the year increases with increase in latitude. For example, at Para (South America) in lat. 1°S., the difference in temperature between the hottest and coolest months of the year is under 3° Fahrenheit, whilst at Verkhoyansk (Siberia), in lat. 67°N., the difference is 120°F.

It should now be quite clear that our summer heat is not due to the comparative nearness of the earth to the sun, for at the summer solstice the earth is furthest away from the sun. The greater warmth of summer in regions away from the Equator is due to the greater length of the period of daylight, to the less oblique impact of the sun's rays, and to the smaller loss of heat by atmospheric absorption. During the winters, on the other hand, temperature is lower because the rays of the sun strike the earth more obliquely, are diffused over a larger area for a shorter interval each day, and are absorbed to a greater extent by the atmosphere.

When the sun has sunk below the horizon, its rays still strike the upper layers of the atmosphere, and are partially reflected back to earth by the minute particles of dust and water contained in the air. This diffused light constitutes *twilight*, and lasts until the sun has sunk about 18° below the horizon. Twilight lasts longer in higher latitudes because the sun does not sink so far below the horizon as it does at the Equator, where it approaches the nadir at all seasons. In England in midsummer, twilight may last the whole night because the sun does not sink 18° below the horizon before dawn commences.

Measuring Temperature

The expressions "3° Fahrenheit" and "120° F." used in the foregoing paragraphs indicate how different intensities of heat or cold, or of "temperature", are expressed in "degrees" (°).

The instrument used for measuring temperature is called a *thermometer*, which consists of a thin glass tube having a bulb at one end. The bulb and part of the tube are filled with mercury or alcohol, both of which expand consistently when heated and contract evenly when cooled. By making use of this characteristic in the thermometer, we

are able to measure variations in temperature by determining the height of the liquid in the tube according to a scale of "degrees" which is either marked thereon or attached thereto.

Various types of thermometer are in general use, but the only important way in which they differ is in the graduation of their scales. The best known types are as follows :—

Scale.	Freezing Point of Water.	Boiling Point of Water.
Centigrade	0°	100°
Fahrenheit	32°	212°
Réaumur	0°	80°

The scale of the Centigrade thermometer, which ranges from 0° to 100°, is highly suitable for use with the Metric system, and, for this reason, is used in all branches of scientific work. The Réaumur scale is now rarely used, but the Fahrenheit scale is still in common use in this country.

Clearly, it is essential to know, when we are considering a temperature quoted in degrees, by what scale it is being measured. On the Centigrade scale the difference between the freezing and boiling points of water is represented by 100°, whereas on the Réaumur scale this difference is indicated by only 80°. Hence 1° Centigrade $= \frac{80°}{100}$ Réaumur.

In comparing either of these two scales with the Fahrenheit scale, a further complication is introduced because on the latter the freezing point of water is represented as 32°. Hence, to convert a Centigrade reading into a Fahrenheit reading for purposes of comparison, we multiply the former reading by $\frac{9}{5}$ and add 32. Conversely, to convert a Fahrenheit reading into Centigrade, we subtract 32 and multiply by $\frac{5}{9}$. For geographical purposes it is the practice to use a thermometer with a scale reaching from about 0° to 120° Fahrenheit.

As the temperature of any given place varies from day to day and even from hour to hour, it is usual for statistical and comparative purposes to calculate an average temperature over a number of years. To arrive at this temperature, a careful record is kept of the maximum

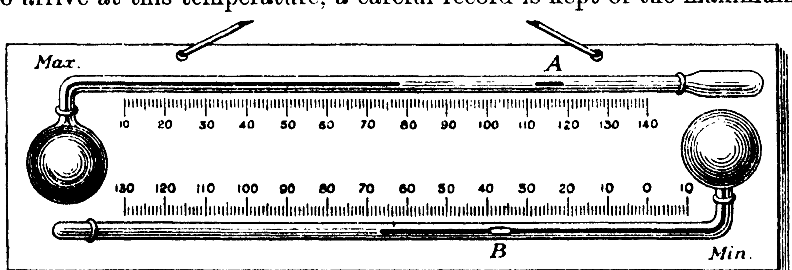

Fig. 59a: Maximum and Minimum Thermometers.

and minimum temperatures recorded at a given place each day, instruments known as Maximum and Minimum Thermometers, of the type illustrated in Fig. 59A, being used for the purpose. The upper thermometer contains mercury which, on expanding, pushes indicator A before it, and, on contracting, leaves it behind. The lower thermometer contains alcohol which, on contracting, drags indicator B back with it, and on expanding leaves it behind. Thus, the inner end of A (*i.e.*, the end of A nearest to the mercury) indicates maximum temperature and the outer end of B (*i.e.*, the end of B farthest from the bulb) indicates minimum temperature.

The average of the daily readings is taken to give the *mean* temperature for each day. At the end of a month, the mean daily temperatures are averaged to find the monthly average temperature. This process is carried out for several years, usually about seven, and the seven average monthly temperatures for the corresponding months of each year are also averaged. The final figures represent the average temperature for each month of the year and these are taken as the standard temperature for that place.

Zones of the Earth

As the decrease in the intensity of insolation as we move from the Equator towards the Poles causes a gradual diminution in temperature, the method has been adopted of dividing up the surface of the earth into five circular bands or temperature "zones" lying parallel to the Equator. These zones, indicated in Fig. 60, are as follows:—

1. THE TORRID ZONE, or the "Tropics", comprising the area between the Tropics of Cancer and Capricorn, *i.e.*, between lats. 23½°N. and 23½°S. Here the sun is nearly overhead all the year round, and there are practically no seasonal differences, either of temperature or of length of day and night.
2. THE TEMPERATE ZONES, comprising the two belts stretching from the tropics to the limit of the Polar regions in each hemisphere, *i.e.*, lats. 23½°N.–66½°N. and lats. 23½°S.–66½°S. In these zones the sun is never quite overhead, and the difference between the lengths of the summer and winter days increases rapidly as the Arctic and Antarctic Circles are approached. From the tropical limits of these regions polewards, there is consequently an increasing difference between summer and winter conditions, and considerable variations in climate are experienced. The forty-fifth parallel of latitude is frequently selected as a convenient line for the division of each of these zones into a *Warm Temperate Zone* in the lower latitudes and a *Cool Temperate Zone* in the higher latitudes.

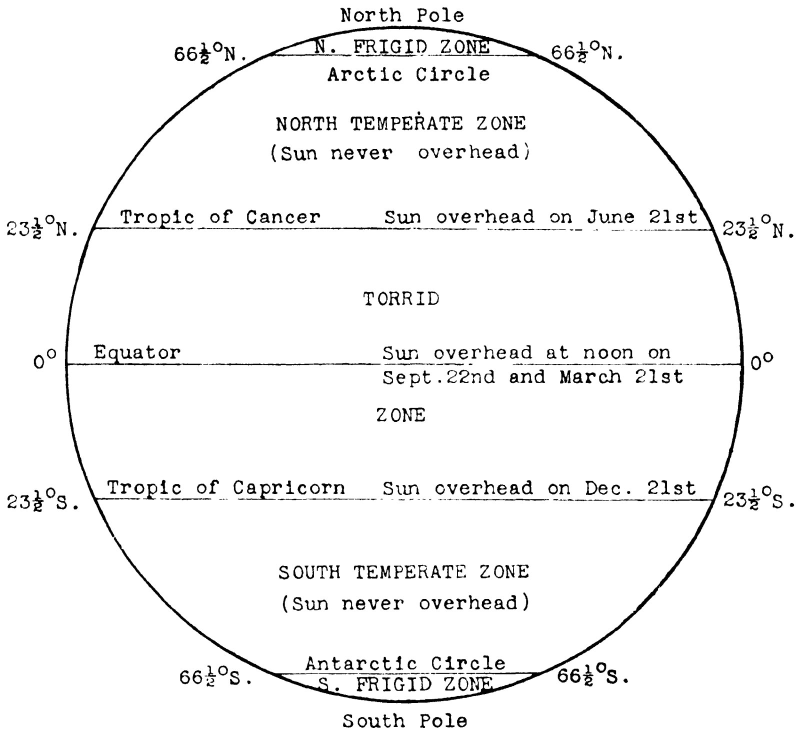

FIG. 60: ZONES OF THE EARTH.

3. THE FRIGID ZONES, or Polar Regions, comprising the area north of the Arctic Circle (lat. 66½°N.) and south of the Antarctic Circle (lat. 66½°S.). In these zones the length of "day" and "night" varies from twenty-four hours at the Circles to six months at the Poles, and the climate is always very cold.

WINDS AND RAINFALL

Pressure Belts

The main factors which determine the distribution of high and low pressure systems are the rotation of the earth, the difference in the heat-absorbing powers of the different parts of the earth's surface, and the differences in insolation according to latitude.

The air at the Equator, being subject to great heat, expands and, becoming less dense, rises to a higher level, thus creating at the Equator a belt of low pressure (the *Doldrums*—Fig. 61). The rising air moves polewards under the influence of temperature (*i.e.*, to cooler regions) and is deflected east by the rotation of the earth. Moreover, centrifugal force is developed by the combined action of temperature and the earth's rotation, and this force tends to drive the air back to the Equator.

As a result of these two opposing forces, the air descends in the latitudes of 30°–40°N. and S., thus increasing pressure in these latitudes. The pressure is further increased by the influence of the earth's rotation, which tends to " press " the air moving from the Equator and the Poles towards latitudes 30°N. and S. Hence, between latitudes 30°–40° N. and S. there are belts of high pressure known as the *Horse Latitudes*—the *Calms of Cancer* in the Northern Hemisphere and the *Calms of Capricorn* in the Southern Hemisphere (Fig. 61).

Around the Polar circles (between latitudes 60°–70° N. and S.) where, with decrease in temperature, we should expect to find high atmospheric pressure, there are belts of low pressure—the *Polar Calms* (Fig. 61)—because the rotation of the earth tends to swing the air away towards the Equator in the upper atmosphere. This air also descends at the Horse Latitudes, thus still further increasing the pressure in those latitudes.

Beyond the Polar Calms pressure again increases, the Poles being high pressure areas due to the intense cold and the decrease in the deflecting force of the earth's rotation.

Winds

As water runs from high levels to low levels, so air moves from regions of high pressure to regions of low pressure, all such movements of the air being known as *winds*. As a result of the distribution of pressure

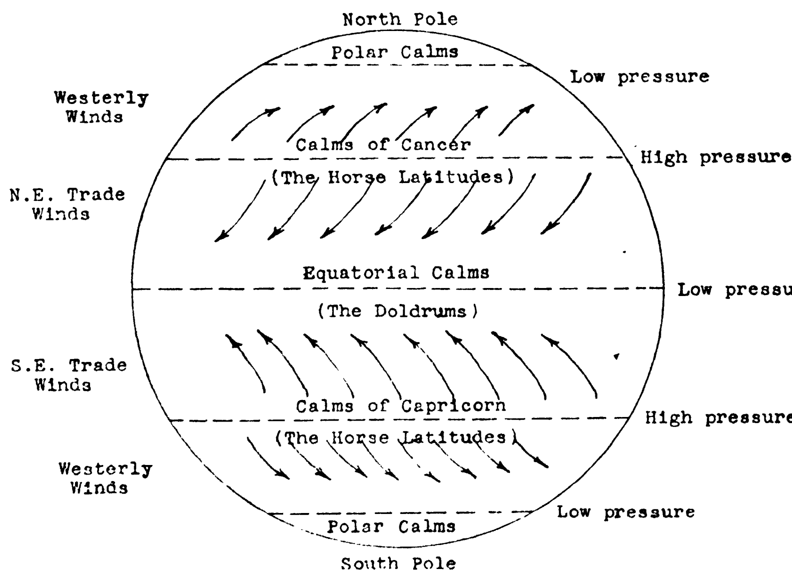

FIG. 61 : PRESSURE BELTS AND WIND SYSTEMS.

described above we should expect the circulation of the atmosphere to consist of winds blowing north and south from the high pressure belts

of the Horse Latitudes to the low pressure areas around the Equator and near the Polar circles. Generally speaking, this is what happens, but the theoretical north-south direction of the winds is modified by three important factors—the rotation of the earth, the influence of large land masses and the apparent movement of the sun north and south of the Equator.

Under the influence of the earth's rotation, the winds in the Northern Hemisphere are deflected towards the *right* of their course, and the winds in the Southern Hemisphere are deflected towards the *left*, the amount of deflection increasing with increase in latitude. The reason for this is that, as the circumference of the earth at the Equator is greater than at any other part of the globe, the linear speed of rotation of the earth's surface is greatest in this region and diminishes towards the Poles. Consequently, winds in the Northern Hemisphere blowing from the Horse Latitudes towards the Equator travel from a region of slower linear speed to a region of higher linear speed, and, as the earth rotates from west to east, these winds are " left behind " or, in effect, deflected towards the west.

Consider, for example, a wind blowing from *a* in the direction of *b* (Fig. 62). The wind has also an eastward velocity equal to the speed of the earth at *a*, but as it journeys in the direction of *b*, the linear speed of the earth is increasing, so that by the time the wind reaches the place

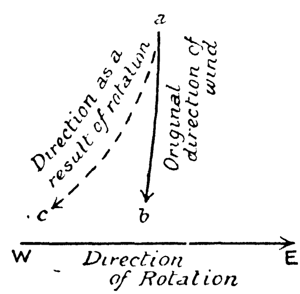

FIG. 62 : EFFECT OF ROTATION ON WINDS.

where *b* was at first, *b* has journeyed farther east than *a*, and the wind, instead of reaching *b*, reaches *c*, which is situated further west.

Thus, winds of the Northern Hemisphere blowing towards the Equator blow from the north-east, and as winds are always named after the direction *from* which they blow, they are called *North-East Trade Winds*, and form part of the regular Trade wind system on which the world's sailing ship trade has been always so greatly dependent.

The effect of rotation on winds blowing north from the Horse Latitudes in the Northern Hemisphere towards the North Pole is to deflect them towards the *east*. Their initial velocity will carry them

farther east than the part towards which they begin to blow, for that region is travelling more slowly than the Horse Latitudes. These winds therefore have an eastward deflection, and as they blow from the south-west or west, they are known as the *Variable* or *South-Westerly Winds*, or *Westerlies*, or *South-West Anti-Trade Winds*.

A similar principle applies to the winds in the Southern Hemisphere, but here, as the winds from the Horse Latitudes blow *north* towards the Equator, they will be deflected towards the *west*, so that, like the North-East Trades, they tend to blow from the east, and, consequently, are known as the *South-East Trade Winds*. The winds blowing towards the South Pole from the Horse Latitudes are deflected towards the east, and are therefore known as the *North-West Anti-Trade Winds* or *Variable Westerlies* or *Roaring Forties*, being similar in origin and direction to the Westerlies of the Northern Hemisphere.

The general arrangement of this " planetary " wind system is shown in Fig. 61, from which it will be seen that in the Northern Hemisphere the direction of the winds is *clockwise*, or to the right of their course, whilst in the Southern Hemisphere it is *anti-clockwise*, or to the left of their course. The general principle thus governing the direction of the winds is *Ferrel's Law* (the same as that applicable to ocean currents), to the effect that *all* bodies moving across the earth's surface tend to be deflected out of their course in the manner described, *i.e.*, clockwise in the Northern Hemisphere, and anti-clockwise in the Southern Hemisphere.

In the absence of disturbing factors the winds prevailing in different parts of the globe would approximately coincide with those shown in Fig. 61. But the irregular distribution of land and sea and the apparent movement of the sun north and south of the Equator give rise to variations from this theoretical planetary distribution of pressure. The alternation of land and water causes an alternation of heat and cold, for land and water absorb and radiate heat at different speeds—water being much more slowly heated and taking much longer to cool than land. These alternations of heat and cold produce corresponding alternations of low and high pressure, which not only affect the force of the winds, but also modify their direction. The influence of large land masses will be more clearly seen when we come to study Monsoons (see p. 137), while the other disturbing factor—the apparent movement of the sun north and south of the Equator—will be considered later in relation to the Mediterranean type of climate (see p. 136).

Rainfall

The atmosphere always holds a certain amount of water-vapour, the gaseous invisible form of water which is formed by evaporation. The greater the heat over a water surface, the greater the speed of evaporation therefrom. Hence, the greatest evaporation of water into the

atmosphere occurs around the Equator, where, too, the warm air is able to hold much more water-vapour than the air in cooler regions.

Even the warmest air, however, has a point at which it cannot hold any more water-vapour, and there is, in fact, such a point for every temperature of the air. In other words, if the temperature of the air were raised by stages 1° at a time, the air could absorb increasing quantities of water-vapour ; but at each successive stage or temperature there would be a point where no more water-vapour could be absorbed. The air at each stage would be saturated with water-vapour, or would have reached its *saturation point* for the temperature concerned. When the air is cold its saturation point is soon reached ; when it is hot, as at the height of summer, it can absorb a great deal of water-vapour before it becomes saturated. Thus the cooling of warm saturated air causes a heavier rainfall than the cooling of saturated air of a lower temperature. This is why so much more rain falls in equatorial than in temperate regions.

The degree of actual dampness of the air we call the *relative humidity* of the air : thus, if we represent saturation point as 100, and say that the relative humidity of the air at a certain place is 50, we mean that the air at that place can hold twice as much water-vapour as it actually does hold at the time. In the hot deserts the relative humidity is 0, because the air is practically dry and could absorb a great quantity of water before it became saturated.

When air containing water-vapour is sufficiently cooled, the water-vapour " condenses ", *i.e.*, assumes liquid form, and it floats in the air on minute dust particles as a visible cloud of tiny drops of water, which are at once deposited on any cool surface with which the cooled air is brought in contact. *Clouds* and *fogs* or *mists* are the result of this condensation of water-vapour, and, once the drops are formed, they tend to become larger by coalescing, until eventually they fall on the earth's surface as *rain*, *hail*, *snow* or *sleet*, according to the degree of cold to which the water is subjected.

Clouds have an important influence on local temperature, for in the day-time they prevent the full force of the sun's rays from reaching the earth, and at night they act as a blanket, restraining the radiation of heat from the earth. Thus cloudless days are warmer than cloudy days, but cloudless nights are colder than cloudy ones. The very thick fogs experienced in London are due solely to the condensation of vapour on the great quantity of dust particles in the London air.

Snow falls when the water-vapour in the air is condensed at a temperature below freezing point, *i.e.*, below 32°F. *Hail* is either a compact form of snow, which occurs in the winter, or solid lumps of ice formed during summer thunderstorms.

Dew is formed in much the same way. The air which on a warm day has become saturated with water-vapour is gradually—sometimes

suddenly—cooled as night falls and it comes into contact with the cooling earth. Then its saturation point quickly falls, and its burden of water-vapour is deposited on the grass and shrubs near the ground as a myriad particles of sparkling water—the dew which in a dry summer is so valued by the farmer. Thus it is that the saturation point is sometimes called the *dew point*—both mean the point at which the air will release part of its content of water-vapour on the slightest fall in its temperature. *Rime* or *hoar-frost* is frozen dew.

The cooling of moist air can be brought about in several ways, *e.g.*, by contact with a cold land surface; by mixing with colder air—as when the warm, moist air from over the Gulf Stream mixes with the cold air over the Labrador Current, causing the frequent fogs of Newfoundland; or by passing from lower to higher latitudes, *i.e.*, from regions of high insolation to areas of low insolation.

All these are important, but the chief cause of the cooling of air is its *expansion*. If the air in an inflated football bladder is suddenly released it quickly expands, and, as it does so, its temperature falls below that of the surrounding air, as we can at once tell by allowing it to blow against our face. Conversely, when air is compressed, its temperature rises—as we realise when a bicycle pump becomes uncomfortably hot, because of the pressure exerted on the air forced into the tube. It will therefore be readily understood that when air rises to a region of lower pressure and expands, its temperature falls and, if it is saturated with vapour, the latter at once condenses and falls as rain or snow.

The successive stages of rain are therefore: (1) evaporation, (2) cooling, (3) condensation and (4) precipitation. In the equatorial low pressure belt, a region of rising air, there is heavy rainfall throughout the year, while in the tropical high pressure belts, regions of descending air, rain is comparatively rare.

Rainfall is measured by means of a *rain gauge*, an instrument which has a funnel-shaped mouth to collect the rain and conduct it into the gauge, which is so constructed that the moisture cannot evaporate or drain away. The amount of rain contained in the gauge can be read off from a scale marked thereon in inches. To determine the annual rainfall of a place, the daily readings are recorded and averaged in the same way as that, already described, which is applied in the determination of temperature figures.

When the average annual rainfall of a district does not exceed 10 inches, the region is said to be dry; an annual rainfall of 50 inches, however, is regarded as heavy. A rainfall of 80 inches is very heavy and rarely occurs except in the torrid zone and in mountainous districts. But a fall of rain which would be considered heavy in the temperate zones would be considered to be only moderate in the Tropics, where evaporation is more rapid.

There are three main types of rain : (i) relief rains, (ii) convectional rains, and (iii) cyclonic rains. *Relief* rains are caused by the deflection of moisture-laden winds upwards by high land. The air currents are forced to rise into the upper atmosphere, where they expand and cool, and part with their moisture. The steeper the slope the heavier will be the rainfall, but the greater rainfall will occur on the lower slopes because there the water-vapour is cooled relatively more rapidly than is the case during its subsequent ascent. *Convectional* rains occur in the hot regions, particularly in the equatorial area. Here the air, continuously heated by contact with the strongly insolated surface of the earth, absorbs a great deal of moisture and rises by convection into the colder regions of lower pressure. There its temperature rapidly falls and its heavy water-content is released as copious rain. In such conditions the moisture falls as rain on or near the area from which it was originally evaporated—conditions which account for the very heavy and almost continuous rainfall of some places on the Equator. *Cyclonic* rains are discussed on page 139.

Winds and Rainfall

Clearly, winds which blow from warmer to cooler regions must raise the temperature of the regions to which they blow ; and, if in their course they pass over the sea, they collect moisture which is deposited as rain in the cooler regions. Thus, the mild, moist climate of the British Isles is due largely to the prevalent South-Westerly winds which blow from the relatively warm body of water in the Atlantic Ocean. On the other hand, winds which blow from cooler to warmer regions will not yield any rain, and will even dry up the land *over which* they pass ; for their moisture carrying capacity increases as their temperature rises. Naturally, too, such winds—of which the Trade winds are the most important—tend to reduce the temperature of the region *to which* they blow.

Trade Winds

The Trade winds blow from the high pressure belts north and south of the Equator towards the equatorial low pressure belt. As we have seen, they are deflected by the rotation of the earth, and blow from the north-east in the Northern Hemisphere, where they are known as the North-East Trade winds, and from the south-east in the Southern Hemisphere, where they are known as the South-East Trade winds (see Figs. 61 and 63).

As these winds originate in descending air currents they are dry at the outset, and, as they travel from cooler to warmer regions, they absorb considerable moisture from the regions over which they pass, and, when they blow across large land masses which are wide enough for their drying influence to exert its full effect, they create arid desert areas. Such desert regions are found in the land masses on either side of the

Equator in the latitudes of the Tropics of Cancer and Capricorn, *i.e.*, in the western and central regions of North Africa, South Africa, Australia, Arabia, Mexico and South America. In all these cases the influence of the winds is the more marked because they have been deprived of their moisture by the highlands of the eastern coasts of the continents by being forced upwards into cooler regions.

Converse conditions exist where the Trade winds reach land after having passed over the ocean. They arrive well charged with moisture, and, if they are forced upwards on meeting high land, they are rapidly cooled and deposit a plentiful rainfall. Regions so affected are the south-east of Africa, including Madagascar, the east and south-east of Australia, the south-east of Brazil, the north-east or Guiana coast of South America, and the West Indies and Central America. The general rule in the Trade wind zones, therefore, is that the east coasts have more abundant rainfall than the west coasts.

Between the wind systems of the North-East and South-East Trades is the equatorial belt of high temperature and low pressure—a region of ascending air currents saturated with moisture, the cooling of which, as we have already seen, results in the heavy rainfall of equatorial lands. This belt of heavy rainfall and great heat moves north and south with the sun—as indeed do all the belts of high and low atmospheric pressure and their accompanying wind systems—and it coincides with the Equator only at the equinoxes.

This phenomenon of the seasonal movement of the pressure belts and winds is known as the " swing of the wind systems ", and its effect, as far as the Torrid Zone is concerned, is that countries on or near the Equator, *e.g.*, the Amazon and Congo basins, the northern lowlands of the Guinea Coast and the equatorial lowlands of Malaya, have two fairly distinct rainy seasons, though there is no really dry season. As the Tropics are approached the interval of time between these two wet seasons gradually decreases until, in the latitudes of the Tropics, there is only one rainy period which runs from the spring equinox to the autumn equinox while the rest of the year is relatively dry. Thus, much of Nigeria, the Upper Guinea lands, the southern part of the Congo basin, the north coast of South America, and northern Australia have a well-defined dry season of five or six months.

Westerly Winds

The Westerly or Anti-Trade winds blow from the Polar limits of the tropical high pressure belts towards the low pressure areas situated on the fringes of the Polar regions, *i.e.*, between lats. 40° and 66½° in both hemispheres. Owing to the rotation of the earth, these winds in the Northern Hemisphere blow from the south-west. In the Southern Hemisphere, the absence of large land masses allows the deflective influence of the earth's rotation to have full effect, and the winds blow

almost due east throughout the year (Fig. 63). On account of their strength and the fact that ships sailing south first picked them up in the neighbourhood of latitude 40°S., the Westerlies of the Southern Hemisphere are known as the *Roaring Forties.*

Between lats. 40° and 66½°, therefore, the west coasts of the land masses, including north-west North America, north-west Europe, southern Chile, Tasmania and the greater part of New Zealand, are wetter and milder than the east coasts. Further, as a result of frequent cyclones (see p. 139) or depressions, most west coast regions in these latitudes receive considerable rainfall, and there are comparatively few deserts. On the other hand, the interior of the land masses in this region, such as central North America and eastern Europe, receive little rain for the winds to which they are subject have deposited their moisture on the land to the west. Such rainfall as is received by these interior regions occurs usually in summer when low pressure conditions over the land masses draw the winds far inland. Even so, the rainfall is very light.

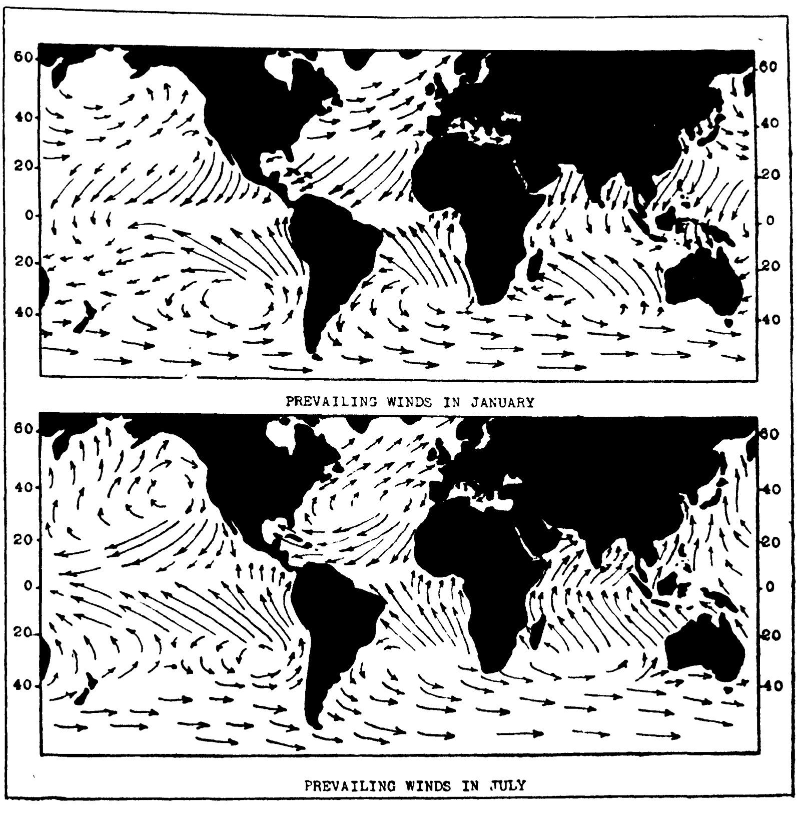

FIG. 63 : PREVAILING WINDS.

The regions under the influence of the Westerlies lie within the two temperate zones. Owing to the movement of the wind systems north and south with the apparent movement of the sun, most of the warm temperate zone in each hemisphere is occupied by the Trade wind belt in summer, while in winter, when the wind systems move towards the Equator with the sun, lands between about lats. 30° and 45° come within the influence of the Westerlies. The west coasts of the land masses in these latitudes therefore receive winter rain from the on-shore Westerlies, whilst in summer they are dry because then they are under the influence of the Trade winds, which have been deprived of their moisture in their passage over land. The climate of western marginal lands in the warm temperate zone is thus characterised by hot, dry summers and warm, moist winters (Fig. 64), conditions which are so typical of the Mediterranean countries that this type of climate is known as "Mediterranean" wherever it occurs.

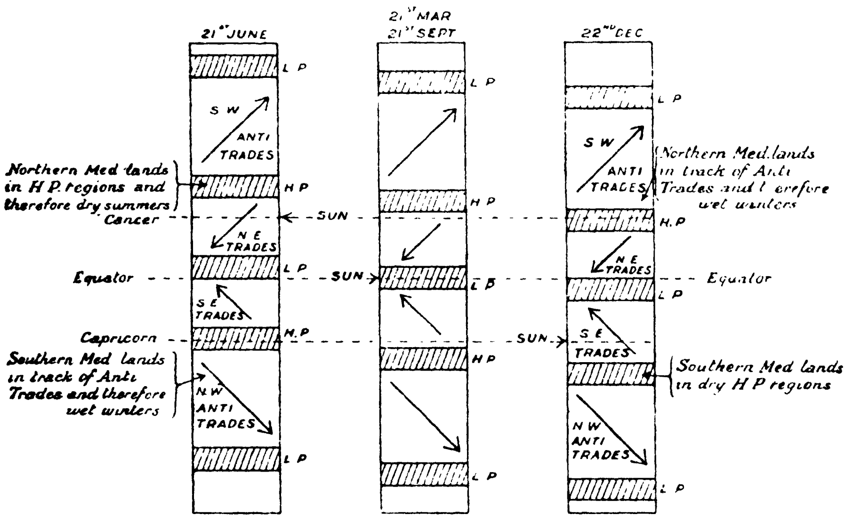

FIG. 64: THE "SWING OF THE WIND SYSTEMS" AND ITS EFFECT ON MEDITERRANEAN LANDS.

The eastern coasts of the continents in similar latitudes receive most of their rain in summer, during the prevalence of the on-shore Trade winds, and they experience comparatively dry winters because then they are in the belt of Westerly winds, which are off-shore to eastern marginal lands between latitudes 30°–40° N. and S. Such are the conditions in Natal, on the coast of New South Wales and in eastern South America in similar latitudes.

Land and Sea Breezes

Hitherto we have considered only those constant or permanent winds which are determined mainly by latitude and earth rotation. We now have to consider winds of a more variable type. There are

certain winds, such as the land and sea breezes experienced on our coasts, that are caused by the difference in the speeds at which land and water absorb and radiate heat. As has been shown, a heated surface warms the air above it and thus causes it to expand and rise, so reducing the local atmospheric pressure and inducing an inflow of cooler air underneath. Conversely, a cold surface causes an increase in atmospheric pressure and induces an outflow of cooler air.

Now the temperature of land rises and falls more quickly than that of water; consequently, on a warm summer day the land, being much warmer than the sea, experiences relatively lower pressure conditions, and an inflow of cool air is forced in from the sea, *i.e.*, a cool breeze blows in from the sea to the land. At night, however, the land cools more rapidly than the sea, the pressure conditions are reversed, and a cool breeze blows outwards from the land over the sea. Generally speaking, therefore, there are during settled weather breezes from the sea by day and breezes from the land by night (Fig. 65).

The Monsoons

These land and sea breezes are of comparatively little importance in themselves, but a knowledge of the way in which they arise is helpful

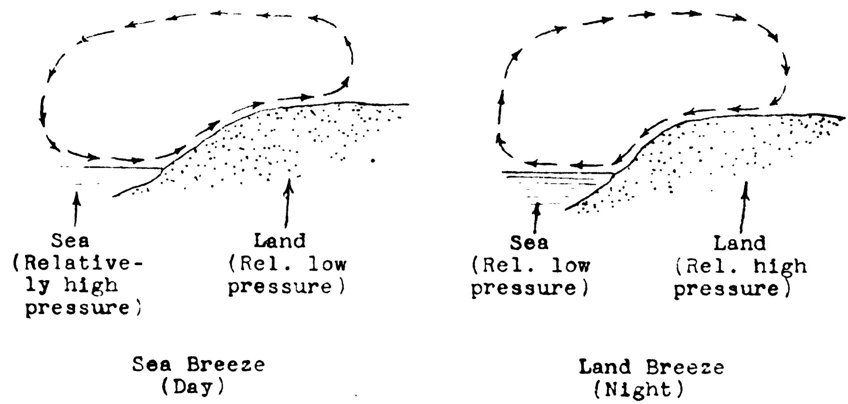

FIG. 65: LAND AND SEA BREEZES IN SUMMER.

in enabling us to understand the vastly important *Monsoons*, or seasonal winds, which are really only land and sea breezes on a large scale, summer and winter taking the place of day and night respectively.

Monsoons are experienced in tropical regions where there are large land masses. The intense heating of the land during the summer sets up low pressure conditions inland, and air is drawn in from over the cooler seas, bringing abundant rain. In the winter the land cools rapidly and experiences relatively high pressure conditions. This gives rise to an air movement from the land to the sea and an outflow of winds which are comparatively dry. In general, therefore, monsoon lands experience

a wet summer and a dry winter during which the wind systems are reversed and the temperature is dependent on local conditions.

From a geographical and economic point of view, the most important monsoons are those of south-east Asia in India, Burma, Indo-China

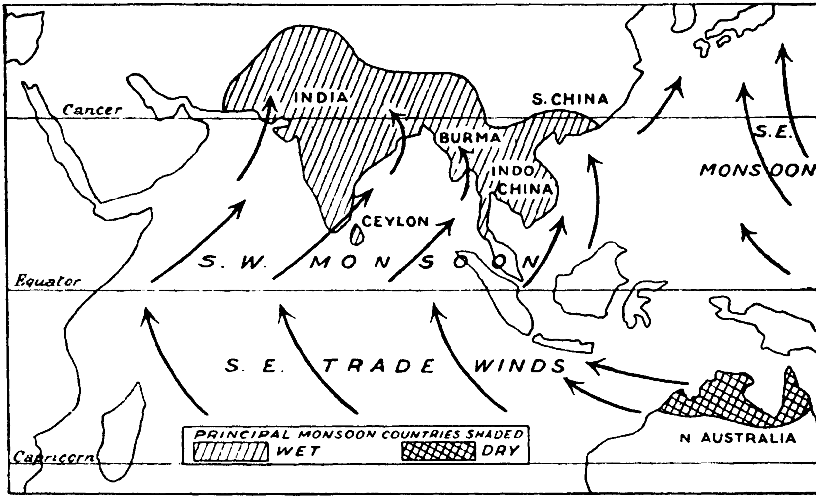

FIG. 66*a*: THE MONSOONS OF S.E. ASIA IN THE NORTHERN SUMMER.

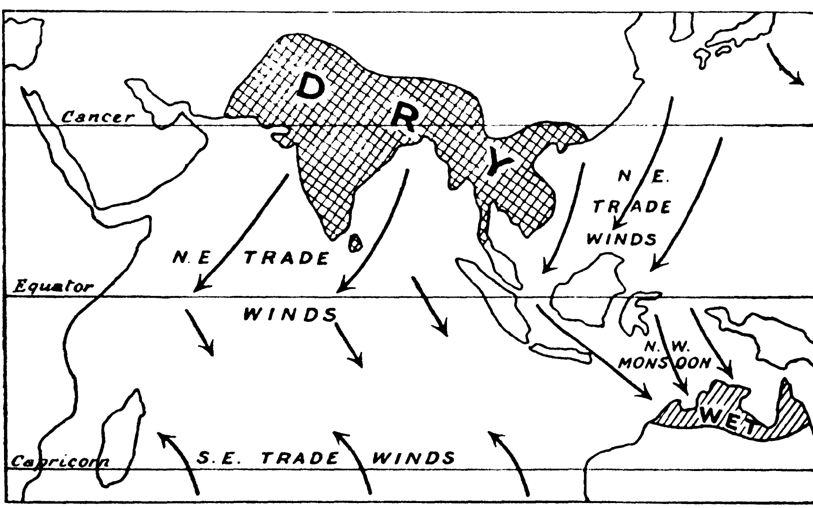

FIG. 66*b*: THE MONSOONS OF S.E. ASIA IN THE NORTHERN WINTER.

and Southern China. In India, Burma and Indo-China the wet *South-West Monsoon* blows from May to September, while the dry *North-East Monsoon* prevails in the winter. Strictly, the South-West Monsoon of India and Burma is a continuation of the South-East Trade winds, which, being drawn across the Equator and deflected

by the earth's rotation, change their direction from South-East to South-West. The North-West Monsoon of Australia is somewhat similarly caused, for it is a continuation of the North-East Trades from the Bay of Bengal, drawn across and deflected as a result of the low pressure conditions prevailing in Central Australia. In Southern China, the wet monsoon blows from the south-east and the dry monsoon from the north-west.

Other monsoon effects occur around the African and American continents. The annual rise of the Nile, which is of such importance to the economic life of Egypt, is due to the heavy summer monsoon rains which fall on the Abyssinian mountains. Again, in the northern summer, the great land mass of North America becomes an area of low pressure, and monsoon effects are noticeable over the Mississippi valley and the south-east of the United States.

The prevailing winds over India and the neighbouring countries for the two periods, July and January, are shown in Figs. 66*a* and 66*b*.

Local Winds

For the reasons explained on page 146, mountain ranges give a special character to local winds, and thus have an important effect on the climate of the areas in their immediate vicinity. These winds are variously named and while some bring heat and dryness, others bring cold and rain. Well-known examples of dry, warm winds are those experienced on the leeward side of the Rocky Mountains (the *Chinook*) and the Alps (the *Foëhn*). (See also Chapter 8.)

Cyclones and Anticyclones

TEMPERATE CYCLONES are depressions which bring rain and unsettled and changeable weather at irregular intervals to the temperate zones, particularly in the Northern Hemisphere. A depression (or " low ") is an area of low atmospheric pressure. Where there is a considerable difference in pressure between the centre and the margins, *i.e.*, when the pressure gradient is steep, the depression is said to be " deep " and the winds will be strong; but when pressure at the centre is not much lower than pressure at the margins, *i.e.*, when the pressure gradient is small, the depression is said to be " shallow," in which case the winds will not be very strong. The winds obey Buys Ballot's law, which states that if, in the Northern Hemisphere, an observer stands with his back to the wind, pressure is lower to the left than to the right; whilst in the Southern Hemisphere, again with his back to the wind, pressure will be lower to the right than to the left. Hence, the direction of the winds is anti-clockwise in the Northern Hemisphere and clockwise in the Southern Hemisphere.

Prior to 1918, the theory of the development and structure of a cyclone was based mainly on the work of Abercromby, an English meteorologist. In this theory, depressions were regarded as regions of " continuous " changes in weather, and although sudden changes

in wind and other climatic conditions were recognised as part of a depression, these changes were not considered to have any influence on the structure of a cyclone.

During the war of 1914–18, Norwegian meteorologists were deprived of foreign weather reports and so were forced to study more closely the weather conditions of their own country. As a result, they discovered that the frequent discontinuities of weather occurring during a depression were closely associated with its structure and they formulated a theory of the structure of a cyclone called the *Polar Front Theory*. This theory, which is now widely accepted, states that the formation of a depression is due to the meeting of a warm sector, *i.e.*, a belt of warm, relatively light air from the south-west (equatorial air) with a cold sector, *i.e.*, a belt of cold, dry, relatively heavy air moving from the north-east (polar air). The cold, heavy air forces its way under the warm air and raises it, the boundary lines between the two sectors being called "fronts"—the warm front to the right and the cold front to the left (Fig. 67). The rising warm air expands, its moisture condenses and conditions become squally with showers of rain. Between the two fronts the weather is cloudy and "muggy," but rain rarely falls. The cold front brings heavy showers, rapidly changing to bright skies, occasional cloud and a low temperature.

The warm sector in a depression, as it is forced up by the cold air, becomes gradually smaller until eventually the two fronts become merged, the points at which they meet being known as the "line of occlusion."

Cyclones, therefore, always become less intense as they move from west to east, while another characteristic is that they frequently occur in a series because the advance of the cold wall forces the polar front further to the south and weaker cyclones develop in the rear of each successive cyclone until the cold air is exhausted in the lower latitudes.

Fig. 67 shows the structure of a cyclone. It will be seen that regions lying between the part of the cyclone marked *AB* will experience one rainy period whilst regions situated in the part of the cyclone marked *BC* will receive two rainy periods (see also p. 163).

The climate of the British Isles is greatly influenced by cyclonic disturbances, a special feature being the occurrence of secondary depressions. These "secondaries," as they are sometimes called, are small cyclones formed within a larger low-pressure system, usually on the southern side of the main depression. They move anti-clockwise round the primary depression with their own wind systems. The intensity of a secondary varies, but the westerly and southerly winds associated with them frequently reach gale force.

Tropical Cyclones cover a much smaller area than the cyclones of the temperate zones, but they are of much greater intensity and occur generally at certain periods of the year. Usually, they are formed in

those tropical regions where the coastline has many indentations, runs north and south, and is flanked to the eastward by a large sea dotted with many islands. The air blows spirally inward and upward, and the storm centre moves along very rapidly until it disappears in the higher latitudes.

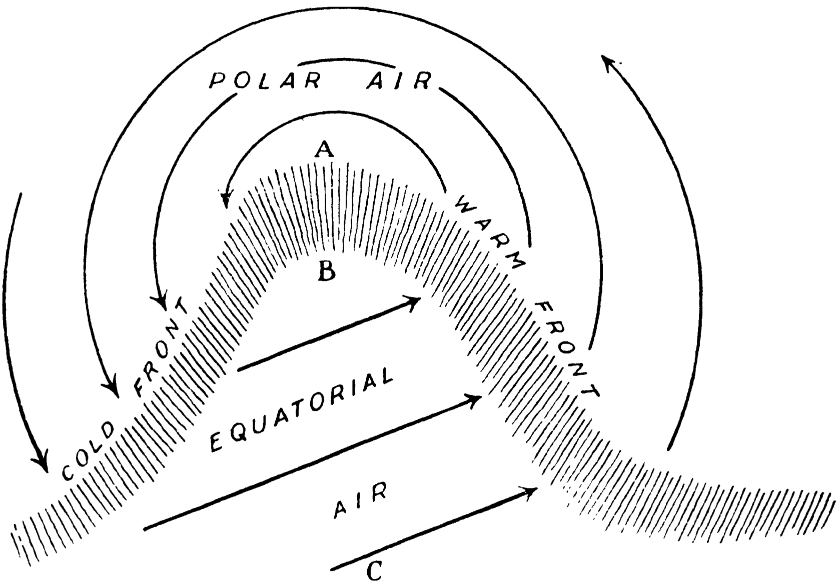

FIG. 67 : CYCLONE: POLAR FRONT THEORY.

The cyclones of the West Indies, which occur generally in August, September and October, are known as *hurricanes* ; those occurring in the China Seas at all times of the year but most frequently from July to October are called *typhoons* ; those of the Indian Seas—most prevalent between January and March—are known as *cyclones* ; and those experienced in the south of the United States, most frequently between June and August, are described as *tornadoes*.

The violent wind which sweeps from the south and south-west across the pampas of South America from July to September is known as the *pampero*. Similar local atmospheric disturbances occur, most frequently during the change of the seasons, in the Sahara and the Arabian Deserts, and are called *simoons*. The *sirocco* is a hot, dust-laden wind drawn northwards from the Sahara by the presence of a cyclone over the Mediterranean. It becomes moist as it crosses the sea and is then particularly oppressive. Winds similar to the sirocco are the *harmattan*, which blows between November and March in the Gulf of Guinea, the *khamsin* of Egypt, the *brickfielder* of Australia, and the *solano* of Spain.

Waterspouts and *sandspouts* are formed by tropical cyclones occurring near the water surface in the former case and near a desert land surface

in the latter case. The great uprush of air at the centre, caused by the whirling action of the wind, draws up a column of water or of sand sometimes to a great height.

ANTICYCLONES are of two kinds. There are the small anticyclones formed between two cyclones because of the comparatively high pressure between them; and those formed when a portion of the sub-tropical Azores High Pressure System becomes detached and moves slowly north-east. The former are naturally not very stable and bring only a few days fine weather between the storms, but the latter, formed of warm, equatorial air, move very slowly and bring long spells of dry weather. During the occurrence of an anticyclone in summer the weather is calm and hot during the day with heavy dews at night; in the winter anticyclones bring calm, cold weather, with frequent frost and fog.

QUESTIONS ON CHAPTER 7

1. Write down what you know of the following:—Monsoon, Trade Winds, Gulf Stream. (*S.A.A. Prelim., May*, 1929)
2. Draw a diagram to illustrate the main wind-belts of the globe, and account for the direction of the winds in these belts. (*C.I.I. Prelim.*, 1928)
3. "The *quantity* of rain decreases, and the *number* of rainy days increases as we go from the Equator to the Pole." Why is this? (*L.A.A. Prelim., June*, 1929)
4. Make a diagrammatic sketch of the prevailing winds of the world. What are the Trade Winds? What effect have they (*a*) over the oceans; (*b*) over the land? (*I.C.W.A. Prelim., Dec.*, 1930)
5. What are monsoon winds and in what parts of the world are they found? Describe their value to the lands over which they blow. (*C.S., March*, 1931)
6. How exactly would you proceed in order to determine the average annual weight of rain water which falls on the Thames catchment area? (*C.S., April*, 1931)
7. Describe, and account for, the chief differences in the seasonal distribution of temperature and rainfall in the *tropics* outside monsoon areas on the one hand and the *north temperate zone* on the other. (*L.M., June*, 1929)
8. Explain carefully the absence of marked seasonal contrasts in the climate in the vicinity of the Equator. (*L.M., June*, 1925)
9. Why are there differences in temperature in various parts of the world at the same time, and in the same area at different times? (*L.M., Jan.*, 1937)
10. Explain clearly why, in the Temperate Zones, the summer season is warmer than the winter season. Diagrams required. (*L.M.*, 1923)
11. What are the characteristic features of (*a*) cyclonic and (*b*) anti-cyclonic weather? State the probable weather changes which would be experienced in summer at London when the central portion of a cyclone passes eastward across the Midland counties of highland. (*L.M.*)
12. Give two examples each of permanent winds, of periodical winds and of variable winds. (*I.C.W.A. Prelim.*, 1936).

CHAPTER 8

WEATHER AND CLIMATE

WEATHER is defined as the condition of the atmosphere *at any moment* with regard to wind, temperature, cloud, humidity, precipitation and similar factors. Since these factors are continually changing it is evident that the weather itself must also vary.

CLIMATE is the *average* condition of wind, rainfall, humidity and temperature, and is expressible for any region or place by striking an average of the conditions experienced over a series of years. Climate plays a most important part in determining the character of the vegetation and animal life of a country, and, to a great extent, the mode of life of its inhabitants. Hence, an understanding of the influence of the main climatic factors is essential to a true study of life and activity in any part of the world.

Factors Affecting Climate

The climate of a region is determined by the combined influence of a variety of factors, of which the chief are :—

1. Latitude.
2. Position of the land relative to the sea or other large body of water.
3. The ocean currents which wash the shores of the region.
4. The prevailing winds.
5. The position and direction of the mountains.
6. The height above sea-level (altitude).
7. The slope of the surface.

The effect of each of these factors is dealt with below, but it must be observed that the climate of a place is the *net* result of a combination of these factors (sometimes with other factors as well), and that it does not depend solely upon any one condition. For example, a low latitude does not necessarily imply a high average temperature; Quito, the capital of Ecuador (South America), is situated almost on the Equator, and yet, owing to its high altitude, it has a climate which is mild and spring-like instead of one which is intensely hot and wet.

Latitude

Latitude, or distance from the Equator, is the chief of the geographical factors affecting climate, for it determines the angle of incidence of the sun's rays—the more nearly vertical the rays, the higher the temperature. This has already been discussed at length, and it is sufficient to note here that, other things being equal, temperature falls as latitude increases.

Position Relative to the Sea or other Large Body of Water

If the earth's surface were composed entirely of level land or of water, all places in the same latitude would be of uniform temperature, which would be higher in summer and lower in winter. But as this is not the case, the distribution of land and water has important effects on climate. Water, as we have seen, is more slowly heated and cooled than land, so that places near large expanses of water are cooler in summer and warmer in winter than places in the same latitude which are not subject to this tempering influence.

Especially marked instances of this exist in the temperate zones. Semipalatinsk, situated in the interior of Eurasia in lat. 50°N., has an extreme climate, with a January temperature of 0°F. and a July temperature of 72°F., whereas Ventnor, in the Isle of Wight, in exactly the same latitude, is quite temperate, with a January temperature of 41°F. and a July temperature of 62°F. In the same way, the Great Lakes of North America greatly temper the climate of places far distant from the sea where we should otherwise expect to find continental extremes of heat and cold similar to those of Semipalatinsk.

Ocean Currents

Ocean currents influence the temperature of adjacent lands only when winds blow over the currents towards the land. If winds blow from a region of warm ocean currents, the climate becomes warm and moist. This is the case with the British Isles, whose mild winters are due to the warming influence of the South-Westerly winds, which not only blow from over the warmer sea but also drive the warm surface-water eastwards as the warm North Atlantic Drift which circulates round the islands. The latter are thus situated in a gulf of warmth stretching into regions which, according to their latitude, should be cold and inhospitable (Fig. 68).

If winds blow onshore from over a cold ocean current they make the land cooler and drier, because the cool wind cannot hold much moisture. In this way, the temperature of western Japan is lowered by winds coming over the cold Kurile current. The direct effect of cold currents on the climate of the countries whose shores they wash is, however, small as compared with that of warm currents, for cold currents usually

flow along coasts experiencing *off-shore* winds. Hence, it is only when weather conditions are sufficiently settled to allow land and sea breezes to develop markedly that the influence of these currents can be carried inland. In other words, the influence of cold currents on the climate of countries is, in the main, indirect. When, for example, the cold Labrador Current meets the warm Gulf Stream off Newfoundland, it

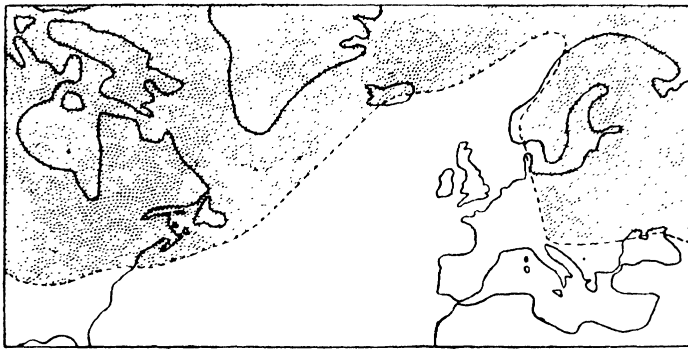

FIG. 68: THE WINTER GULF OF WARMTH IN THE NORTH ATLANTIC. *The area shaded has an average January temperature below freezing-point.*

produces considerable fog which is very troublesome to navigators, but it has no effect on the climate of the interior of Canada or the United States, since the prevailing winds on the North Atlantic seaboard of those countries usually blow *from* the land *to* the sea. Nevertheless, this current assists in lowering the temperature of Labrador itself owing to the effect of daily land and sea breezes and of cyclones, while it also causes the closing of the St. Lawrence by ice during the winter.

Prevailing Winds

The winds which blow over a country have an extremely important effect on its climate, for they are carriers of both heat and moisture. Winds blowing from the land do not carry moisture, but they influence climate by lowering or raising the temperature according as they blow to a warmer or to a cooler region. Winds blowing from a warm sea bring both moisture and warmth, whilst if they blow from a cool sea they are dry and lower the temperature of the land.

The part played by the prevailing winds in modifying the effects of proximity to masses of water is also important in that they may either completely eliminate the direct effect of adjacent water, or may greatly intensify and extend that influence. (See also Chapter 7.)

Position of Mountain Ranges

The chief climatic effect of mountain ranges—as also of any steeply rising land, such as the approach to a plateau—is that which they have

on rainfall. Mountains which lie across the path of moisture-laden winds force them to rise, and the consequent expansion and cooling of the air result in the condensation of the water-vapour which they carry, and its deposition as rain on the *windward* slopes. In this way the coast ranges of British Columbia, for example, produce an abundant rainfall for the coastal lowlands, while the Southern Alps of New Zealand have a similar effect on the rainfall of the western side of South Island.

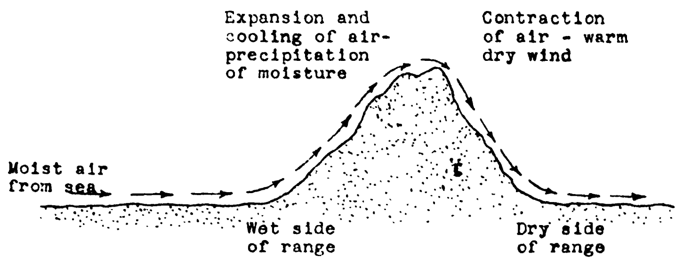

FIG. 69 : EFFECT OF MOUNTAINS ON RAINFALL.

The climatic effects on the *leeward* side of mountains or plateaus are, however, just the reverse. There the winds which have just crossed over are forced to descend to the plains and the air of which they are composed is compressed and warmed. This increases its moisture-bearing capacity and causes it to reach the plains on the leeward side as a relatively warm and dry wind (Fig. 69).

When, therefore, an originally moist wind blows over high land in the manner described, the windward side of the mountains tends to have a heavy rainfall, whereas the leeward side tends to be comparatively dry. For this reason, places on the leeward side of mountains are said to lie in the *rain shadow* of the hills.

The warm, drying winds which blow on the landward side of mountains have frequently a highly beneficial effect, as, for example, the winds of the *Foëhn* or *Chinook* type.

THE CHINOOK wind blows eastwards from the Rocky Mountains down to the neighbouring Provinces of Canada, and, as it is most prevalent in winter and spring, it greatly modifies the cold of winter, and often causes a rapid disappearance of the snow over a comparatively wide area. Parts of the high plains in Alberta are thus made available for grazing much earlier in the year than would otherwise be the case.

THE FOËHN, a local wind which blows northward over the Alps early in the year, is a strong current of air formed as a result of cyclonic disturbances over Central Europe. Its initial temperature is relatively high, and as it descends the leeward side of the mountains fairly rapidly it does not lose much heat by radiation or conduction. Hence, it reaches the northern Alpine valleys as a hot, dry wind, which melts away the

snows of the valleys much earlier than they would otherwise be cleared. The *Berg* of South Africa is similar to the Foëhn, and a wind of similar origin occurs in New Zealand where it blows from the New Zealand Alps and reaches the Canterbury Plains as a hot, dry wind.

THE BORA and MISTRAL. Other winds of similar class but of reverse effect are the *Bora* of the Alps and the *Mistral* of Southern France. These two winds are cold, as they originate during the winter from plateau land in the north and north-west which has a higher barometric pressure than the adjacent valleys, and their descent of the leeward side of the mountains is not enough to warm them very much.

The important sheltering effect of mountain ranges is well illustrated by the Himalayas. These mountains, with an average height of about three miles, extend for about 1,500 miles across the north of India and act as an immense climatic barrier sheltering India from the cold winds which sweep over Tibet throughout the winter months. Were it not for these mountains the winter climate of Northern India, instead of being mild, would be bitterly cold. Agricultural operations, which now extend over the whole year, would have to be discontinued during the winter months, and India's teeming millions would find it even more difficult than they do now to eke out a bare subsistence on the soil.

The Himalayas afford the most outstanding example of the effect of mountains as climatic barriers, but, as will be seen from Fig. 70, similar conditions are found throughout the world. The Alps shelter the Mediterranean lands from the cold northerly winds, and so ameliorate

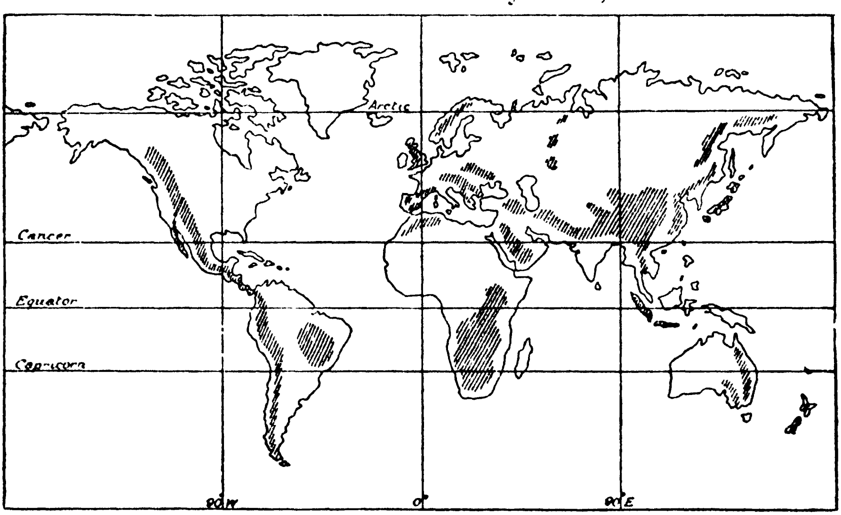

FIG. 70: CLIMATIC BARRIERS.

their winters, although the climate experienced to the north of the Alps is cold and rigorous. In North America the absence of such a barrier in the north makes nearly all the continent liable to experience sudden

changes of temperature from mild to bitterly cold, as a result of a sudden veering of the wind from south to north. The cold north winds, known as " cold waves ", are felt as far south as the Gulf of Mexico and the south-east coast, where their effect is sometimes very serious. In Florida, particularly, the season's orange crop is occasionally destroyed by frost as a result of the influence of these northerly winds.

[*Photo by W. F. Taylor.*

ETERNAL SNOW MID EQUATORIAL JUNGLE.

Though the top of Mt. Kilimanjaro, E. Africa, is clothed in eternal snow, its feet lie in land which is covered with equatorial jungle and where the heat is so great that only the scantiest clothing need be worn.

Height above Sea-Level

As the atmosphere is dependent for its warmth on the degree to which the surface of the earth is heated by the sun, it will be apparent that temperature will drop with increase in height above sea-level, for the warm air rising from the earth's surface gradually cools, while in the higher altitudes, the atmosphere is thinner and therefore cannot hold as much warmth as the lower and thicker layers of air.

It follows, therefore, that the greater the altitude of a place, the lower the temperature of that place. If this were not so, there would be no such thing as a snow-capped mountain, but actually there is in fact

on the average a decrease of 1°F. in temperature for every 300 feet of increase in altitude.

It is this modifying influence of altitude which makes what would otherwise be extremely hot places within the Tropics healthy and habitable by white men, and renders high land in the temperate zones bleak and inhospitable or even completely uninhabitable. Whereas Mombasa (East Africa), for example, situated almost at sea-level 4° from the Equator, has a mean temperature in the hottest month of 80°F., Bogota (Colombia, South America), also situated 4° from the Equator but at an altitude of 8,700 feet, has a temperature for the same month of only 58°F. In the temperate zones, regions such as the highlands of Scotland are bleak and of little economic value, chiefly owing to the effect of altitude.

Slope of the Surface

The general slope of the land, like altitude, has either a modifying or an accentuating action on the effect of latitude. We have seen that in low latitudes, *i.e.*, near the Equator, the sun's rays strike the earth almost at right angles and so concentrate their heat on a smaller area than in higher latitudes, where they fall more obliquely, and consequently, have a larger area to heat. If the surface of the land slopes so that it faces the sun, the obliquity of the rays is counteracted, and the area to be heated by a given number of rays is more restricted. On the other hand, if the surface slopes away from the sun, the obliquity of the rays is accentuated, and the area to be heated is more extensive. In Fig. 71, equal amounts of sunshine fall on areas 1, 2 and 3, but as the

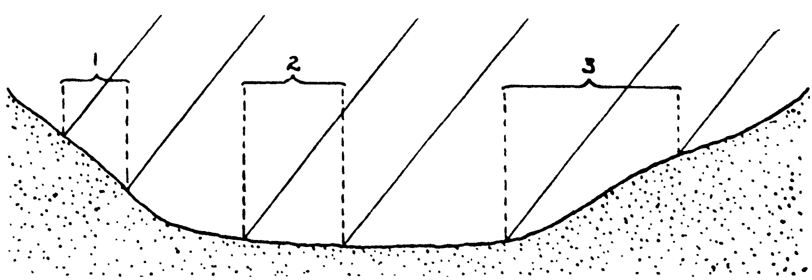

FIG. 71 : EFFECT OF SLOPE ON CLIMATE.

degree of concentration of the rays varies with the slope of the land, 1 receives the most heat per square foot and 3 the least. The effect of the slope of land is, therefore, to decrease or increase the temperature of the area concerned according as the surface slopes towards or away from the sun. In the Northern Hemisphere, north of the Tropic of Cancer, where the sun always lies to the south, slopes facing south are warmer than level country, and level country is warmer than slopes facing north. The reverse conditions, of course, apply in the Southern Hemisphere.

A good example of the effect of slope is found in the Plain of Lombardy, in Northern Italy. The northern part of this plain slopes to the south and experiences a milder climate than the southern part, which slopes to the north.

Deserts

Those regions of the earth which have not enough rainfall or which are too cold to support useful vegetation are called *deserts*. Those which are characterised by little or no moisture and extreme heat are known as ***hot deserts***, whilst those which are caused mainly by intense cold are known as *cold deserts*. The hot deserts, as stated previously, extend in a belt round the earth north and south of the Equator, though mainly to the north owing to the more extensive land masses in the northern hemisphere. They lie, as a general rule, on the west side of continents, out of reach of rain-bearing winds, and in many cases (*e.g.*, the Sahara Desert and the Desert of Peru) their aridity is accentuated by the effect of cold currents in the neighbouring seas. Owing to the lack of cloud, the days are intensely hot, but as the sun goes down the heat is rapidly radiated away and consequently the nights are extremely cold. There is a similarly marked difference between summer and winter temperatures.

The cold deserts include the almost lifeless wastes of perpetual ice and snow, known as *ice deserts*, which surround the poles, and the bordering regions, known as the *Tundra*, which have a brief summer when the surface thaws and a few plants burst into life. There is a further group of deserts called the *temperate deserts*, which owe their existence to relief or high altitude.

The characteristics of deserts are dealt with in Chapter 9, and at this point it is sufficient merely to notice the main causes which lead to a lack of rainfall. We know that the cause of rainfall is the cooling of moist air which has risen and expanded. In some deserts there is no moisture in the air, whilst in others, though moisture does exist in the air, there is no means by which the air can be induced to rise and deposit its vapour content as rain. We can therefore class deserts according to the cause of lack of rainfall.

HIGH PRESSURE AND TRADE WIND DESERTS. Nearly all the great hot deserts of the world lie in the belts of high pressure, from which winds tend to blow away. In this class is the desert of *Arabia* in South-Western Asia, the greater portion of which is in the track of the dry North-East Trade winds, but whose southern area, known as the *Dahna* desert, is practically windless all the year round. In no part, however, do sea winds cross the land for any length of time.

The great *Sahara* desert of northern Africa and the *Kalahari* desert of South Africa are both of this high pressure type (Fig. 72). They lie

beyond the reach of the Westerly wind belts at all seasons, while the prevailing easterly winds are robbed of their moisture by lands further east before they reach the desert areas. The *Great Australian* desert and the *Colorado* desert of North America fall in this same

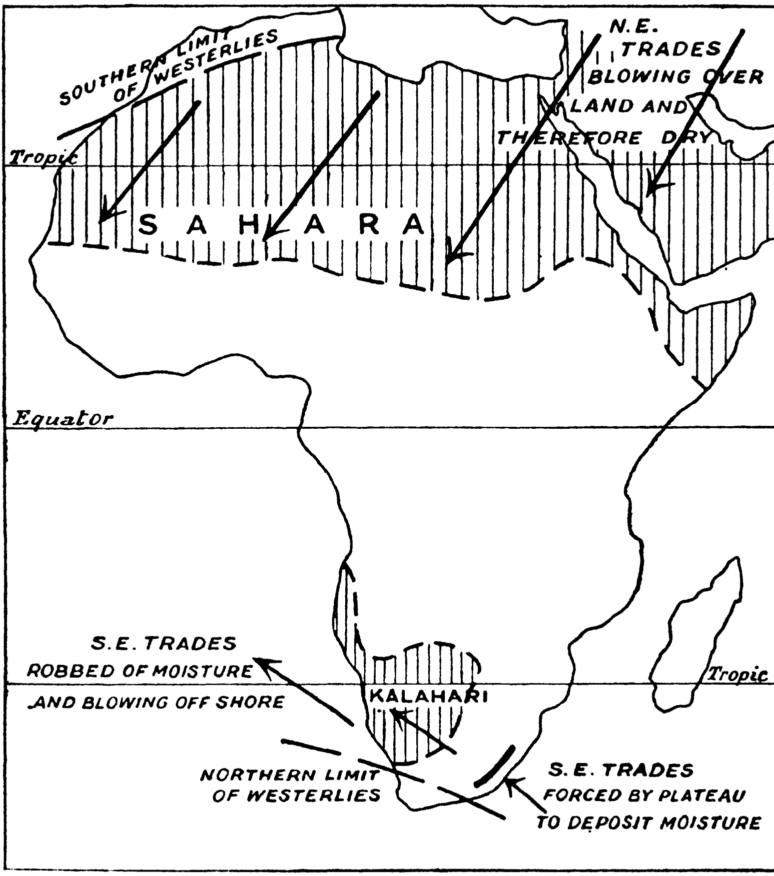

FIG. 72: THE DESERTS OF AFRICA.

group, and in both these cases the desert conditions are accentuated by the existence of mountains on the east and by the elevation of the land.

DESERTS ON THE LEE OF MOUNTAIN RANGES include the hot *Atacama* desert of northern Chile, where the South-East Trade winds blow from the Atlantic Ocean but are forced to deposit their moisture on the eastern slopes of the Andes; and the temperate *Patagonian* desert of the southern Argentine, where the Westerly winds which blow from the

Pacific at all seasons deposit their moisture on the western slopes of the Andes and reach Patagonia as dry winds (see Fig. 73).

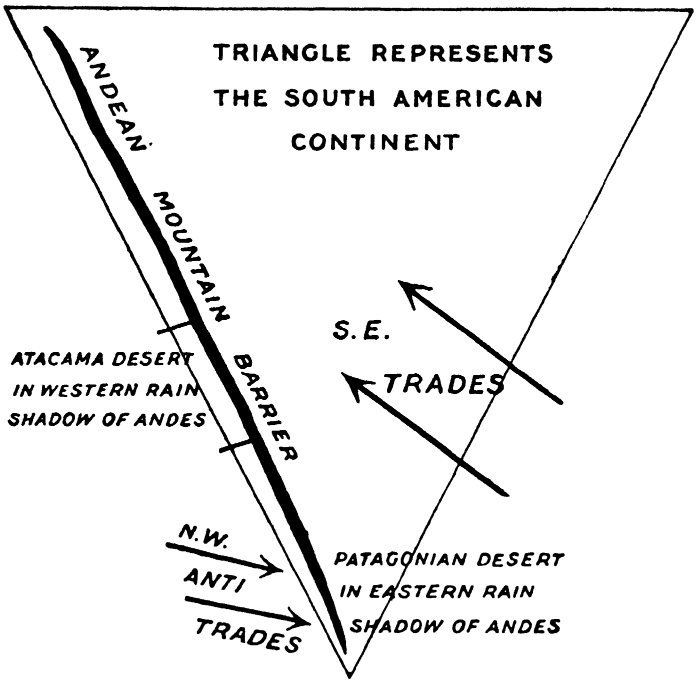

FIG. 73 : DIAGRAMMATIC EXPLANATION OF THE DESERTS OF SOUTH AMERICA.

LOW-LYING AND SEA LEVEL DESERTS. In low-lying lands outside the areas of cyclonic winds there is nothing to force the air to rise, and, consequently, even though there is moisture in the air, it does not condense and no rain falls. Such areas are found both inland and near the coast. An inland example is the *Aral-Caspian* depression in the south-east of European Russia, which does not possess sufficient highland to cause condensation. An example near the coast is the hot *Thar* desert in the lower valley of the Indus (India), which is so flat that, though it lies near the sea with on-shore winds, it is nevertheless practically rainless.

TABLELAND DESERTS. When a moisture-laden wind reaches a tableland it is forced to rise, its moisture is deposited as rain or snow on the windward slope of the tableland or plateau, and it reaches the interior as a dry wind. This occurs in regions such as *Iran*, *Afghanistan* and the *Pamirs*, where there are temperate deserts receiving very little moisture. That which they do receive is usually in the form of snow, for, owing to their high altitude, these regions are subject to great extremes of temperature.

MOUNTAIN GIRT DESERTS. Interior regions shut off from the oceans by high ranges of mountains do not receive rain at any season of the year. Such conditions prevail in Asia to the north and north-west of the Pamir and Tibetan ranges. In this region there is a string of deserts, of which the most important are the *Takla Makan* and the *Gobi* deserts—both temperate.

COLD DESERTS. Within the Arctic Circle stretch the *Tundra* or frozen deserts of the north. Here, the desert conditions are due almost entirely to the fact that the region is nearly always subject to dry winds, especially in winter, when the snowfall is generally equivalent to less than one inch of rain. In summer, the northerly movement of oceanic depressions brings some rain, and during the brief period of comparative warmth the surface becomes covered with quickly growing mosses and lichens.

Irrigation

The soil of the deserts is not always infertile, and, as a rule, it is merely lack of rain or extreme cold that makes such regions useless for cultivation and settlement. The cold deserts cannot be reclaimed and made to serve man's needs because their temperature is too low; but the hot deserts provide one of the few instances where human skill has been able to overcome climatic conditions, and, in many places, these areas have been made to produce valuable crops by means of *irrigation.*

Where irrigation is employed man has been able to exercise an almost complete control over the crops grown, and the great sums of money expended in conveying water to the barren areas have been, or are in process of being, amply repaid. But whilst irrigation has proved of immense utility in supplying water to desert regions, it is perhaps still more important in regions where the rainfall is *precarious*, *i.e.*, where it is *usually* adequate but where it sometimes fails, bringing famine and misery to the large populations already settled there. In parts of India and Australia, for example, a failure of the rains would, in the absence of irrigation, cause ruin of the harvests, and in India, with its dense population, this would bring misery and even death to large numbers of people.

Systems of irrigation are numerous. The most elementary form is *flood irrigation*, which consists merely in permitting the flood waters of a river to cover the land on its banks and so not only to water it but also to fertilise it by the deposit of alluvium and silt brought down by the floods. This system, if it can be so described, was practised for centuries in the ancient civilisations of the Nile Valley and of Mesopotamia. Nowadays, the most important form of irrigation is that known as the *perennial canal system*, which involves the construction of sluices and canals to carry water from the rivers to the arid land. This system, which is now widely used in the valleys of the Nile, the Euphrates,

the Tigris and the Ganges, has the disadvantage of not fertilising the land in the same way as flood irrigation, for the canal system does not carry and deposit on the land the rich alluvium which is brought down and deposited by flood waters. Dependent on the great Sennar or Makwar dam is the extensive Gezira (Sudan) irrigation scheme, a classic example of this type of irrigation work.

Another important method involves the use of *storage tanks* and *reservoirs* to store water collected during the rainy season to meet the scarcity of the dry season, as is practised in southern India. Here, again, there are disadvantages, for in very hot seasons the tanks and reservoirs dry up, whilst in a bad rainy season they do not fill properly. Similar disadvantages are present in the *inundation canal system*, in which canals are constructed from a river to catch the flood water, a method used in northern India. In most cases, however, inundation canals are being replaced by perennial canals.

IRRIGATION IN THE LOWER HIMALAYAS.

On the steep slopes of the outer Himalayas, great industry has been shown by the hardy hill men in terracing and preparing land for cultivation. The labour and expense involved have been enormous, but the reward is reaped in the richness of the soil and the facility with which the terraces are irrigated. In spring wheat is reaped, and then the fields are flooded for rice. Often two varieties are sown, the autumn rice and the winter rice; the former being harvested in September, the latter in December.

Artesian wells (see p. 50) are frequently employed for irrigation purposes (*e.g.*, in Australia, Picardy, the London Basin and Texas), while in some areas, *e.g.*, Western U.S.A., dams and tunnels through mountains are utilised. In Baluchistan, underground tunnels known as *karez* have been built to intercept and store the water which comes from the hills and which would otherwise drain and evaporate away, and to carry it to the fertile plains, where the rainfall is scarce.

In the Deccan, the Upper Yangtse-Kiang (China), and the eastern counties of England, irrigation is practised by raising the water from *wells* by means of buckets, wheels or wind pumps. *Terrace irrigation* is employed chiefly in the famous Red Basin of China (Sechwan), where the water is carried either naturally or by mechanical means to the topmost terrace and is let down as required by little sluices to the lower terraces.

The advantages to be obtained from the employment of irrigation are numerous. It ensures a regular and constant supply of water and a consequent increase in the yield of crops. Whereas some available water is quite unsuitable for irrigation because of the harmful compounds it contains, irrigation water usually contains fertilising chemicals, which help to increase the crops, while flooding methods themselves sometimes remove undesirable constituents from the soil. Moreover, irrigation has often made it possible to replace old crops by more valuable ones which cannot grow to perfection without a plentiful water supply.

In general, irrigation makes it economically possible to devote more labour and capital to the preparation of the soil, for there is less risk of failure through lack of the necessary moisture, and the inherent fertility of the soil can be fully utilised. Again, where the temperature permits, cultivation can be carried on throughout the year, and, thanks to the increased moisture, the period of growth is much shorter, with the result that a greater number of crops can be grown in a given period. This applies particularly to "Mediterranean" and monsoon lands. In southern California and western Arizona, for example, farmers can sow their crops at any time during ten months in the year, and three crops of potatoes can be grown on the irrigated land in one season. There is thus a tendency towards a greater concentration of population in irrigated areas than in areas which are similarly situated but in which irrigation is not practised ; and where the farmer can choose his season for sowing, he will naturally sow at a period which will enable him to market his produce at a time when comparative scarcity, and therefore high prices, prevail. This tends to minimise price fluctuations and to lessen the risk of serious scarcity.

Climate and Forests

It is a debatable point whether or not forests have a direct influence on rainfall, but there is little doubt that they do have a general effect on local climate. In equatorial forest regions, for example, they have an

equalising effect in lowering the ground temperature during the hottest part of the year. In other parts of the world, regions which were seldom subject to frosts have received annual visitations after the cutting down or destruction of forests on surrounding hills, doubtless because these areas have been thereby exposed to the influence of cold winds.

The fact that forests act as barriers to the winds, and so protect valuable crops, is applied in many parts of the world where belts of trees have been planted at right angles to the prevailing winds to act as " windbreaks ". Trees are particularly useful in hot countries to shelter plants from hot, parching winds and from the direct rays of the sun, *e.g.*, banana trees are frequently planted in hot countries to protect the coffee plant from the fierce heat. Again, in areas protected by forests, rainwater and other soil moisture are conserved (for vegetation checks the rate of " flow-off "), while the network of roots makes the surface soil less easily washed away. In addition, forests act as a check to rapid evaporation and increase relative humidity—particularly in equatorial areas.

The planting of trees as a protection from the elements is therefore another of the ways in which man is able to exercise a controlling influence on the effects of weather and climate. The most recent experiment in this direction is being made in Palestine. At present, the rain which falls on the rocky, treeless hills of that country collects to form rapid torrents. These denude the land of the little soil that remains and carry it away to the coast where it blocks the waterways and forms unhealthy marshes, in which malaria thrives. By the systematic planting of trees it is hoped to lessen the downflow of surface water and encourage it to filter through the soil to subterranean channels, by which life-giving springs at the valley heads will be fed. The roots of the trees will bind the soil together and thus lessen denudation, while the dead tree vegetation on the ground will act as a reservoir for moisture and will, in time, itself become fertile soil.

WEATHER CHARTS AND CLIMATIC MAPS

A weather chart is a map of the weather conditions of a region over a stated period. Such a chart can be made for the whole world or for a small district only, such as the British Isles, and is usually constructed for a period of twenty-four hours. From the study of such a chart we can form a correct view of the kind of weather experienced during the period concerned, and by a correct reading of the various symbols or indicators employed, we can forecast the type of weather likely to be experienced for a limited period afterwards. These indicators are of various kinds.

Isopleths

Isopleths are " lines of equal distribution ", *i.e.*, they are lines drawn on the surface of a map to connect all places having one feature in

common. Thus, contour lines are isopleths, because they join all those places on a map which have the same height above sea-level. The isopleths used in connection with weather are *isotherms*, *isobars* and *isohyets*.

ISOTHERMS (" equal heat ") are lines joining places having the same average temperature for a given period of time. In maps, they are usually shown either for the whole world or for a certain area and cover the months of January and July (see Figs. 74 and 75). As a rule, isotherms do not record the *actual* average temperatures, but those temperatures after they have been adjusted or " reduced " to sea-level by adding 1°F. for every 300 feet of altitude above sea-level. In other words, isotherms indicate what the average temperature of an area would be during a given period *if it were a flat surface at sea-level.* Unless this fact is constantly borne in mind the information obtained from temperature maps will be totally misleading. Daily isotherms are not used on maps, but monthly mean temperatures are given in some atlases.

As temperature decreases north and south of the Equator, isotherms *tend* to run parallel to lines of latitude. This is more noticeable in the Southern Hemisphere with its vast expanses of sea, but in the Northern Hemisphere, while the general direction of the isotherms is east to west, greater irregularities occur, because there is far more land than sea and because the two are very unevenly distributed. In both hemispheres isotherms are deflected by those influences which affect climate, such as winds, ocean currents, land configuration, and nearness to the sea.

Figure 74 shows that the isothermal lines for January bend north over the sea and south over the land. At this period, the Northern Hemisphere is experiencing its winter season, and the Southern Hemisphere its summer season. In the former, therefore, the land is cooler than the sea, whilst in the latter the reverse is the case, and this is shown by the isothermal lines. The area of greatest heat on land lies between about 15°N. to 25°S., for during this period the sun appears to move to its farthest south position. It should be noticed how far south the isotherm of 80°F. runs over the land of the Southern Hemisphere. On the African plateau, of course, the *actual* temperature is much lower than 80°F. because of the height of the land above sea-level. There is a very pronounced northward bend of the lines over the sea in the Northern Hemisphere, clearly illustrating on the one hand the warming influence of the sea and, in particular, of the North Atlantic Drift, and the cooling influence of the land masses on the other. Iceland, for example, just south of the Arctic Circle (lat. 66½°N.), has the same mean temperature (32°F.) as the southern part of North America, which is situated between lats. 30° and 40°N.

A further noticeable point is that the isothermal lines run nearly north and south in the vicinity of the British Isles. This is largely because of the land mass to the east, the expanse of warm water to the west, and the influence of the prevailing winds. These three factors even

out the temperature of different parts of the Islands and also make the temperature of the Islands as a whole much less severe at this period than that experienced in the centre of the land mass of Eurasia.

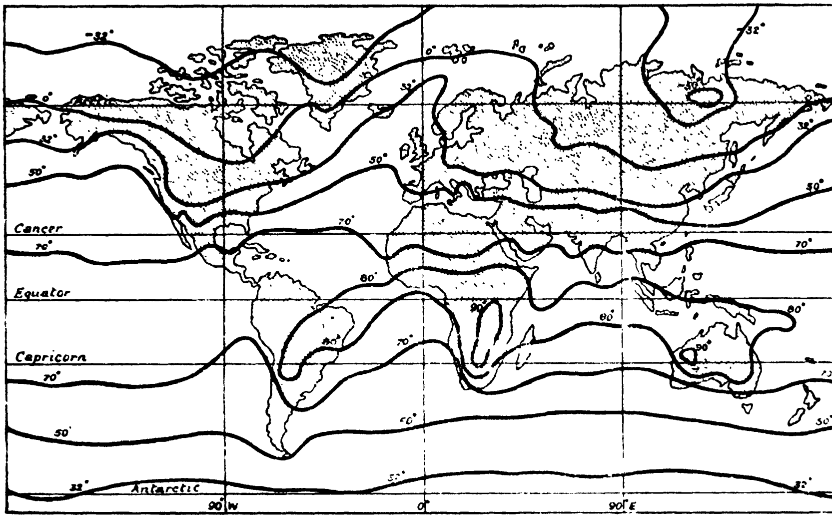

FIG. 74 : SEA-LEVEL ISOTHERMS FOR JANUARY (APPROX. IN DEGREES FAHR.).

In the Southern Hemisphere, the isotherm of 32°F. and that of 50°F. are, in comparison with those of the Northern Hemisphere, relatively straight lines. In the south, the isotherm of 32°F. follows the Antarctic Circle but around the Arctic Circle, except for a small area off Scandinavia, the temperature is much below freezing point, and over a large area it is even below zero.

In July, the Northern Hemisphere is experiencing its summer and the Southern Hemisphere its winter. At this period the 80°F. isotherm, which, as in January, is a continuous line completely enclosing the area of great heat, is situated almost entirely north of the Equator. Again the effect of the height of the land of south-eastern Asia must be allowed for in considering this isotherm as in the case of Africa in January. The lower isothermal lines are still comparatively straight in the Southern Hemisphere, and the isotherm of 32°F. is nearer the South Pole than its counterpart in the Northern Hemisphere in January is to the North Pole. This is due to the large expanse of water in the lower latitudes of the Southern Hemisphere. The general tendency in the Northern Hemisphere is for the isotherms to bend north over the land and south over the sea, owing to the existence at this period of greater heat over the land masses than over the sea. The direction of the isotherms in the vicinity of the British Isles is perpendicular to their direction in January. They now run east and west, with an inclination towards the south over the sea.

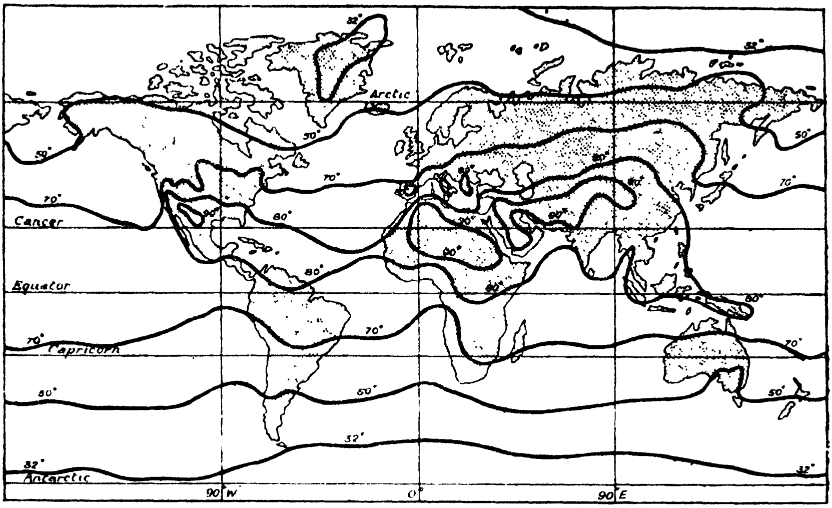

FIG. 75: SEA-LEVEL ISOTHERMS FOR JULY (APPROX. IN DEGREES FAHR.).

Isothermal lines are not used in the daily weather charts issued by the English press (see p. 162).

ISOBARS are lines drawn on maps to connect places where the mean height of the barometer at sea-level is the same, or, in other words, where the atmospheric pressure would be the same if all the places were at sea-level. Winds are caused by differences in barometric pressure, and these differences, as stated in Chapter 7, may be recorded by taking barometric readings at intervals. Isobars drawn to represent average pressures over a given period of time will therefore indicate the course of permanent and seasonal winds.

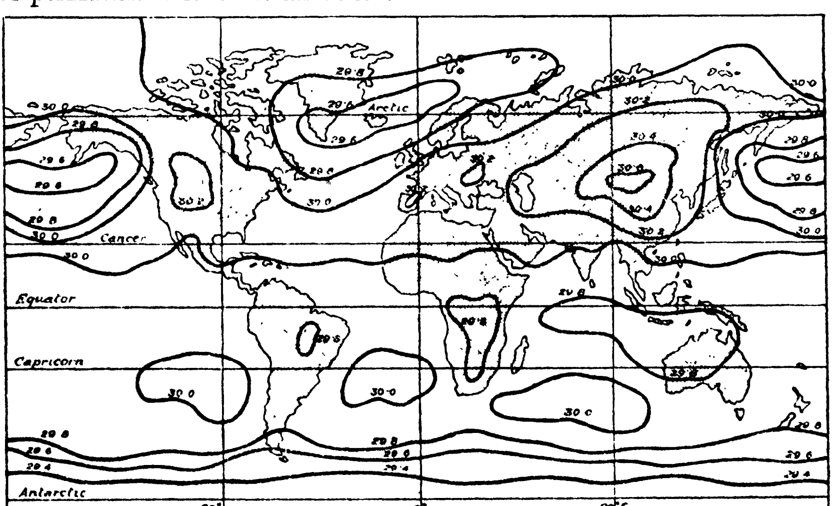

FIG. 76: SEA-LEVEL ISOBARS FOR JANUARY (APPROX. IN INCHES).

As in the case of isotherms, isobars are usually shown on maps as an average adjusted to sea-level for the months of January and July, and they are so shown in Figs. 76 and 77 respectively. These figures should be compared with Fig. 61, which shows the theoretical high pressure belts.

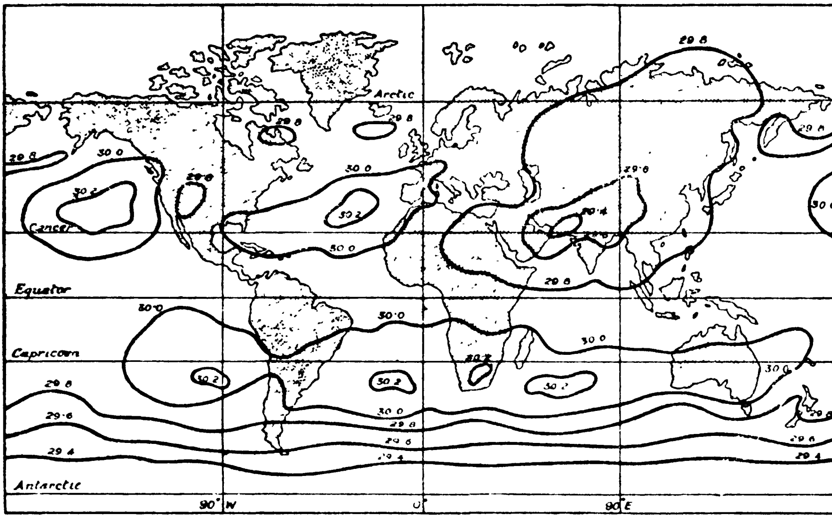

FIG. 77: SEA-LEVEL ISOBARS FOR JULY (APPROX. IN INCHES).

On weather charts the isobars show the *actual* pressure at the period represented by the chart. Where the isobars are close together, a strong wind is indicated as the pressure changes rapidly; where they are wider apart, a gentle wind is indicated, as the pressure changes more slowly. On these charts, isobars are shown at intervals of 4 millibars, a millibar representing a pressure of about .03 inch, and 1,016 millibars a pressure of 30 inches. Weather forecasts are based chiefly on a study of isobars (see p. 162).

ISOHYETS are lines drawn on a map to connect places with equal rainfall. They are not used to any great extent, however, as it is usual to show differences in the distribution of rainfall on maps by means of shading, differences in colour, or some similar method, while, on weather charts, the daily or other periodic rainfall is shown by means of symbol letters (see p. 162). Fig. 78 shows the distribution of the rainfall of the world in July by means of variations in shading, and a careful study of this in conjunction with a map of world relief and a map of prevailing winds will demonstrate clearly the importance of the influence of altitude and of wind systems on the distribution of rainfall.

"Beaufort Scale" and "Beaufort Notation"

A study of a weather chart (see Fig. 79) will show that, in addition to the isobars and remarks such as "Low", "High", "Barometer

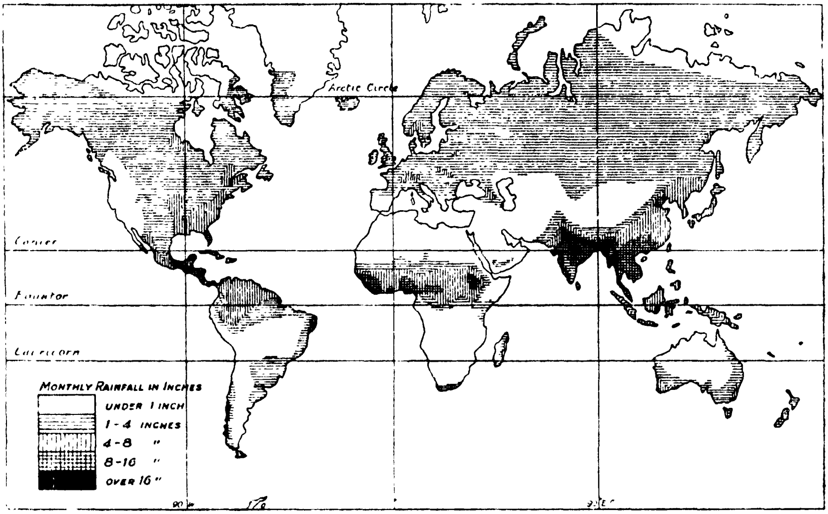

FIG. 78 : WORLD DISTRIBUTION OF RAINFALL FOR JULY.

rising slowly ", " Barometer falling slowly ", which indicate the distribution of barometric pressure and the tendencies of change, there are various isolated numbers, letters and arrows. The isolated numbers indicate the temperature in different parts of the area covered by the chart, while the arrows indicate the direction and force of the winds. The length and number of " feathers " on the arrows vary in order to indicate the force of the wind as given by means of numbers in what is known as the " *Beaufort Scale.*" A short feather indicates one number and a long feather two numbers in the Scale, *e.g.*, an arrow with one short and two long feathers indicates the number " 5 " in the Scale. The numbers in the *Beaufort Scale* are from 0–12 and their significance is as follows :—

Beaufort Scale

BEAUFORT NO.	SPECIFICATION. *General.*	SPECIFICATION. *At sea.*
0	Calm	Calm
1	Light air	
2	Slight Breeze	Light Breeze
3	Gentle breeze	
4	Moderate breeze	Moderate breeze
5	Fresh breeze	
6	Strong breeze	Strong wind
7	High wind	
8	Gale	Gale forces
9	Strong gale	
10	Whole gale	Storm forces
11	Storm	
12	Hurricane	Hurricane

The isolated letters which appear on the charts are part of what is known as the "*Beaufort Notation*" and indicate the general weather conditions in their neighbourhood, as distinct from wind conditions. Their meaning is given below.

Beaufort Notation

b Blue sky (not more than a quarter of the sky covered).
bc Sky partly cloudy (one half covered).
c Generally cloudy.
d Drizzle, or fine rain.
e Wet air without rain falling, a copious deposit of water on trees, buildings, or rigging.
f Fog.
g Gloom.
h Hail.
l Lightning.
m Mist.
o Overcast sky.
p Passing showers.
q Squalls.
r Rain.
rs Sleet, *i.e.*, rain and snow together.
s Snow.
t Thunder.
u Ugly, threatening sky.
v Unusual visibility. The horizon or distant hills unusually clear.
w Dew.
x Hoar frost.
y Dry air (less than 50 per cent. humidity).
z Dust haze; the turbid atmosphere of dry weather.

Analysing Weather Charts

We can, it is evident, obtain a great deal of information from a weather chart, such as that reproduced in Fig. 79, which is a specimen

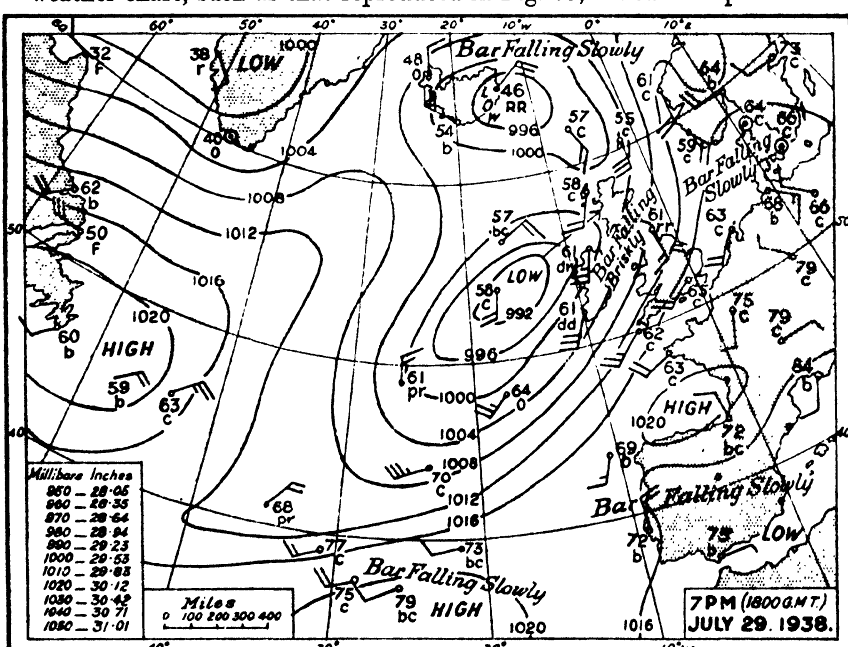

FIG. 79: WEATHER CHART.
REPRODUCED, WITH THE OFFICIAL WEATHER FORECAST, FROM THE *Times*, WITH THE PERMISSION OF THE PROPRIETORS.

of those published by the *Times*. This chart is based on observations at 7 p.m. (summer time) on 29th July, 1938, and the weather forecast for the following 24 hours as deduced therefrom and given by the newspaper was as follows :—

" GENERAL INFERENCE FROM OBSERVATIONS AT 7 P.M.—A depression to the west of Ireland will move north-eastwards across the British Isles. Weather will be rather warm and close generally, with rain or drizzle at times in most areas."

" Forecasts for Today".

" LONDON, ENGLAND, S.E., E., MIDLANDS, E., W.—Wind south-west, moderate to fresh ; some bright intervals, local drizzle ; warm and close.

" ENGLAND, S.W., WALES, S.—Strong south-west wind, gale locally ; cloudy, local coastal fog and drizzle ; rather warm and close.

" ENGLAND, N.W., WALES, N., SCOTLAND, S.W., W., N.W., ISLE OF MAN.—Strong south-west winds, gale locally at first ; cloudy periods, occasional rain ; rather warm and close.

" ENGLAND, N.E., MIDLANDS, N., SCOTLAND, S.E., N.E., MID, ORKNEY AND SHETLAND.—Fresh to strong south-west winds ; cloudy, occasional rain ; rather warm and close.

" PROVISIONAL FORECAST FOR SUNDAY.—Unsettled."

Fig. 80 shows the isobars and wind directions during the prevalence of a cyclone over the English Channel, and Fig. 81 shows similar features at a period when the British Isles are under the influence of an anti-cyclone. Both are typical of the conditions occurring in the late summer or early winter.

A feature of all cyclonic weather is the change in the direction of the winds. This occurs because the low pressure in the centre of the cyclone attracts winds from all directions and as the cyclone moves so must the winds vary at any particular place lying in the path of the cyclone. In Fig. 80 the cyclone is moving north-east and thus the winds at a place lying in the track of the centre of the cyclone will change or veer from north-east through east to south-east, then to south and through south-west to west. Fig. 80 also shows that the wind directions are not the same at other places over which the disturbance passes, *i.e.*, places not in the direct path of the centre of the cyclone. In the Midlands of England, for example, the winds will change from north-east to north, then to north-west and finally to west.

Barometric changes are more frequent when the isobars are close together than when they are farther apart. Hence, when a map shows the isobars close together, *i.e.*, when the barometric gradient (as it is called) is steep, the winds will have greater force than when the isobars are shown farther apart. In Fig. 80, the isobars are much closer together in the rear of the cyclone than in front of it, hence the force of the winds will increase as the centre of the disturbance approaches and will not moderate until some time after it has passed.

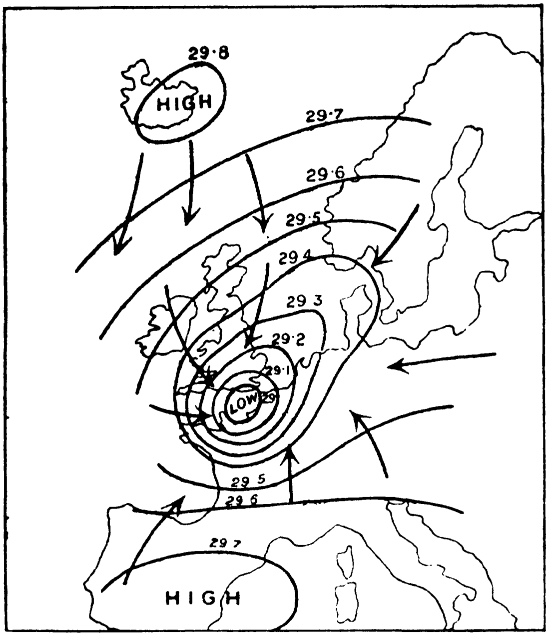

FIG. 80: ISOBARS AND WINDS IN CYCLONIC CONDITIONS.

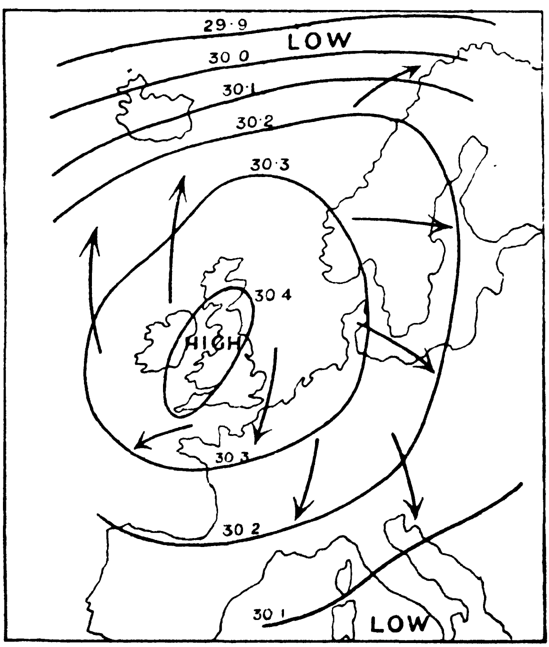

FIG. 81: ISOBARS AND WINDS IN ANTI-CYCLONIC CONDITIONS.

The conditions shown in Fig. 81 will give fine weather and light winds because, during anti-cyclonic conditions, the barometric changes are much less frequent than is the case during the prevalence of a cyclone.

QUESTIONS ON CHAPTER 8

1. On what does climate depend? (*L.A.A. Prelim., June,* 1929)
2. State not less than four important factors determining climate. (*C.I.I. Associateship, Life Branch,* 1928)
3. What are isobars? Draw diagrams showing a probable grouping of isobars on a British weather chart during a period (*a*) of stormy weather, and (*b*) of fine, calm weather. Annotate your diagrams. (*C.S., April,* 1930)
4. Construct a weather chart to show a low pressure system centred over Eastern Scotland, a secondary depression crossing Southern England and a high pressure system over France. Interpret your chart so as to indicate the probable direction of the winds and other weather conditions in (*a*) Dublin, (*b*) London. (*L.M., June,* 1926)
5. What is meant by (*a*) isotherms, (*b*) isobars? With the aid of a sketch-map explain how an isobar-map can give a general idea of the wind movement over the British Isles. (*L.M.*, 1928)
6. What is an isothermal line? Under what circumstances would you expect the direction taken by an isothermal line to vary most widely from that of a parallel of latitude? Give actual examples of such variation in support of your answer. (*L.M.*)
7. Describe the kind of weather that would probably occur in the British Isles in winter if there were very high barometric pressure over Iceland and a cyclonic system, centred in the English Channel, over Western Europe. Make a sketch showing approximate isobars and wind-directions. (*L.M.*)
8. How is temperature usually shown on maps? Give an account of the steps by which you would accumulate data for a map of the July temperature in the British Isles. (*L.M.*)
9. Describe the influence of a cold sea current on climate. (*C.I.I. Associateship, Accident Branch,* 1931)
10. Indicate an ocean area characterized by very high atmospheric pressure in summer and one characterized by very low atmospheric pressure in winter. (*C.S., April,* 1930)
11. State and account for the physical changes that moist air undergoes in rising over a mountain range and in descending the other side. Give instances of areas where these changes are most marked. (*L.M.*, 1923)
12. What are the more important facts shown upon a weather chart such as that issued in the *Daily Weather Report* and how are these facts obtained? What is the practical value of such a chart? (*C.S., April,* 1935)

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